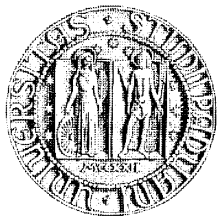

UNIVERSITY OF PADOVA

Master Thesis in Physics

GAIA GALAXY SURVEY

SIMULATED OBSERVATION OF GALAXIES WITH ESA GAIA SATELLITE

Mattia Vaccari

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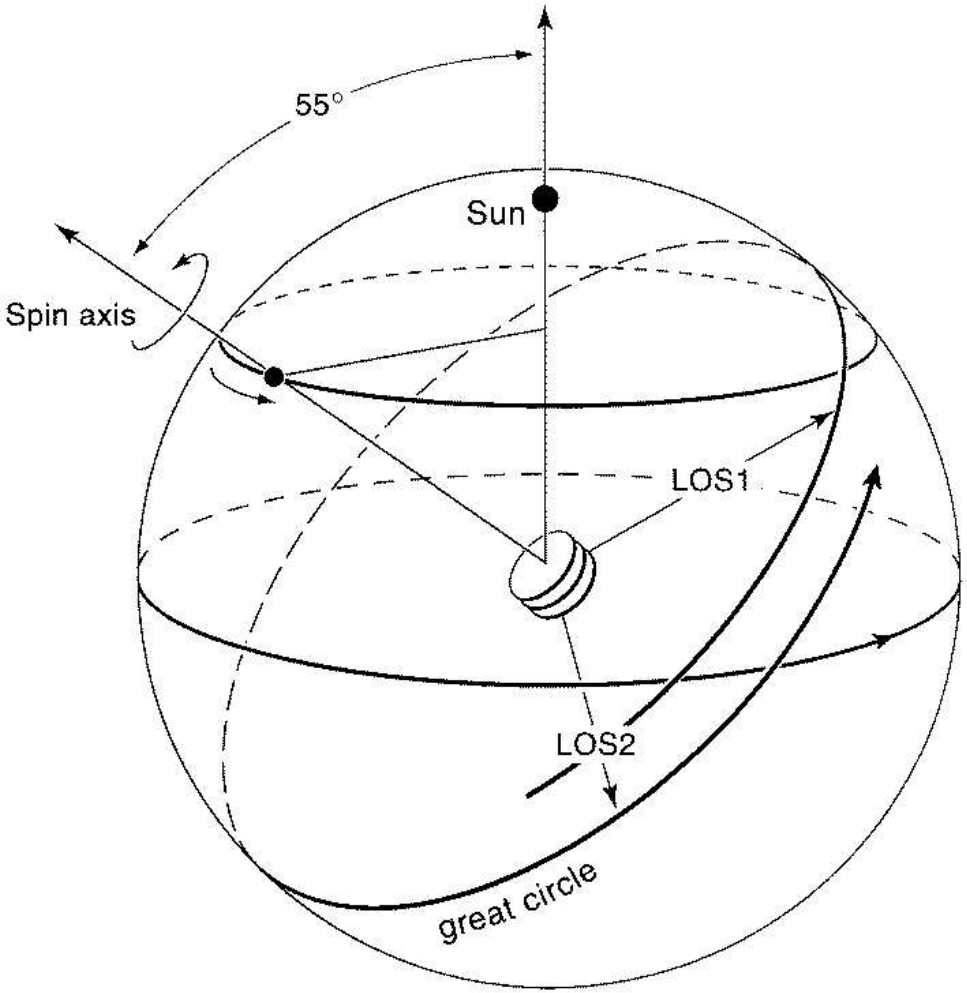
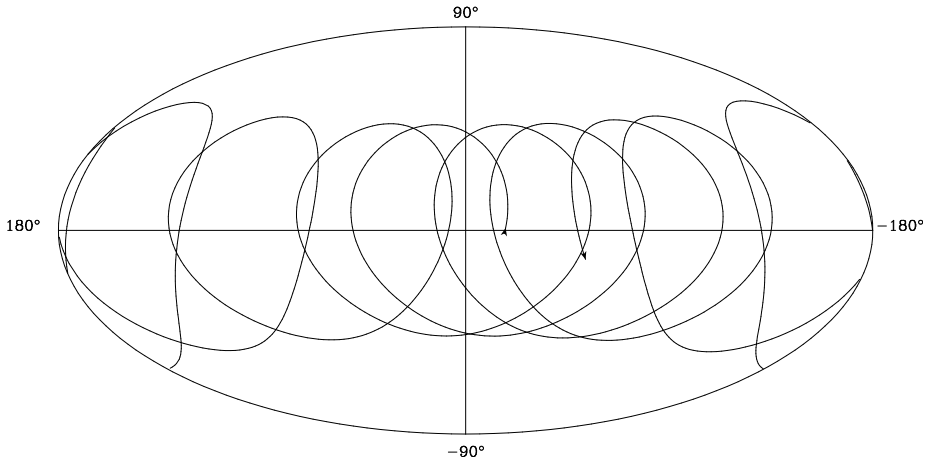
Department of Physics	Astronomical Observatory	Department of Astronomy
University of Padova	University of Copenhagen	University of Padova

Scanning Law (1)

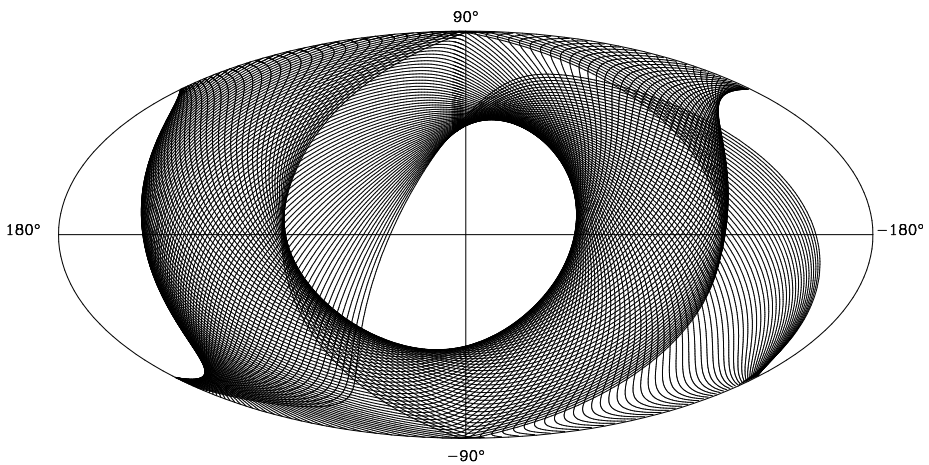


- The scanning of the sky by the satellite is obtained through the combination of two motions:
  - A spin of the satellite about its symmetry axis with $T_{rot} = 3$ hours
  - A precession of the satellite spin axis about the Sun-Satellite direction with $T_{pr} = 72$ days

Scanning Law (2)



• Motion of the spin axis in 4 months



• Sky Coverage in $T_{pr} = 72$ days

$\Downarrow$

• On average every sky region is observed 85 times in 5 years

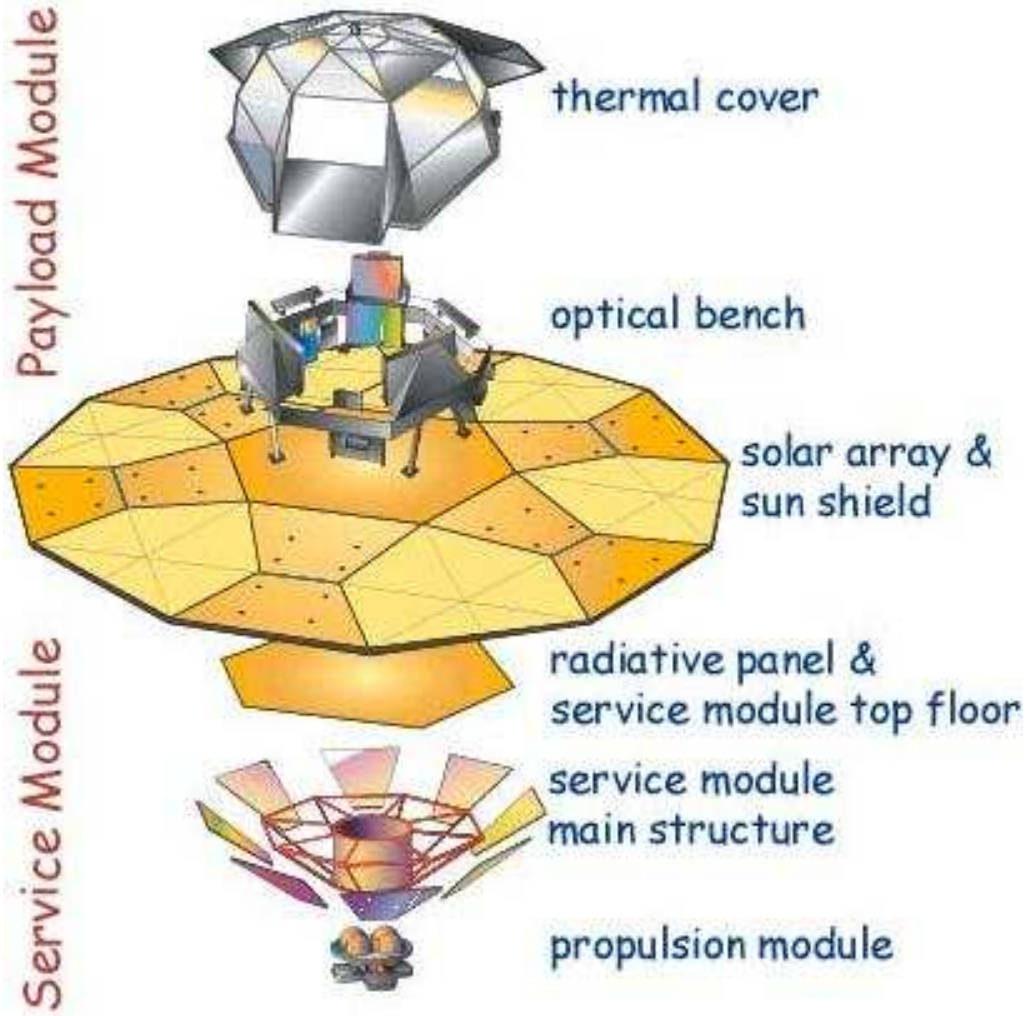
$\Downarrow$

• Reconstruction of parallactic and proper motions

• Detection of possible photometric and spectroscopic variability

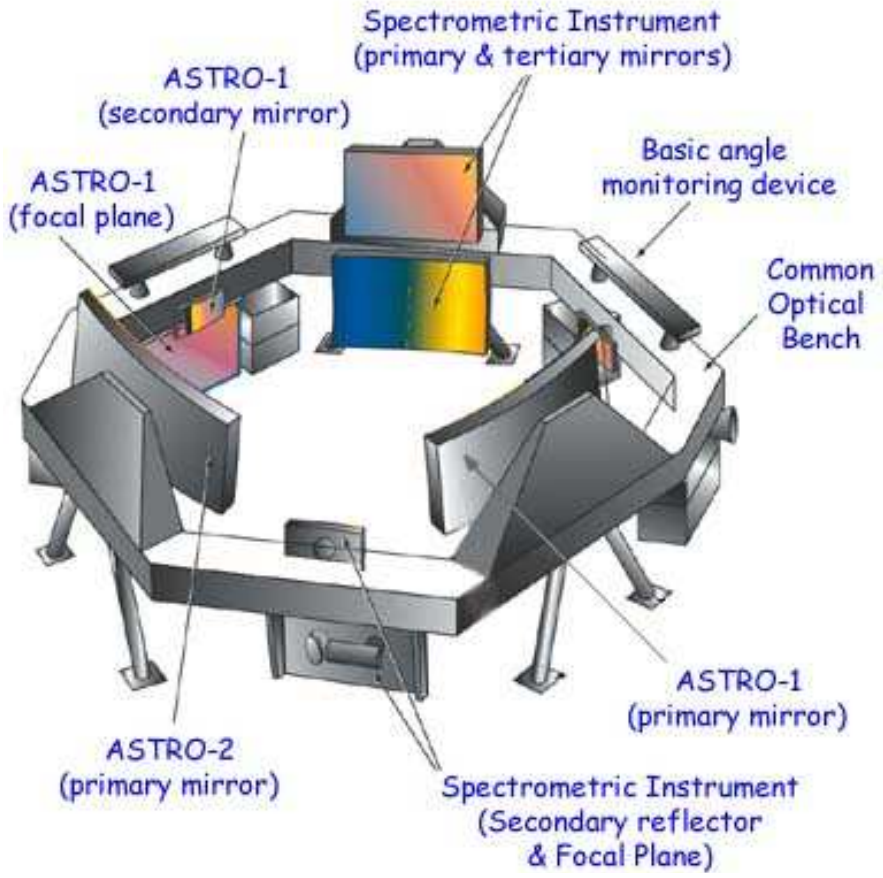
• Nominal accuracy achieved at the end of the mision only

Spacecraft



- Dual launch with Ariane 5 in 2009
- Lissajous orbit at L2 point of Sun-Earth System
- Operational lifetime: 5 years
- Telemetry rate: 1 Mbit/s on average (20 Tbyte in 5 years)

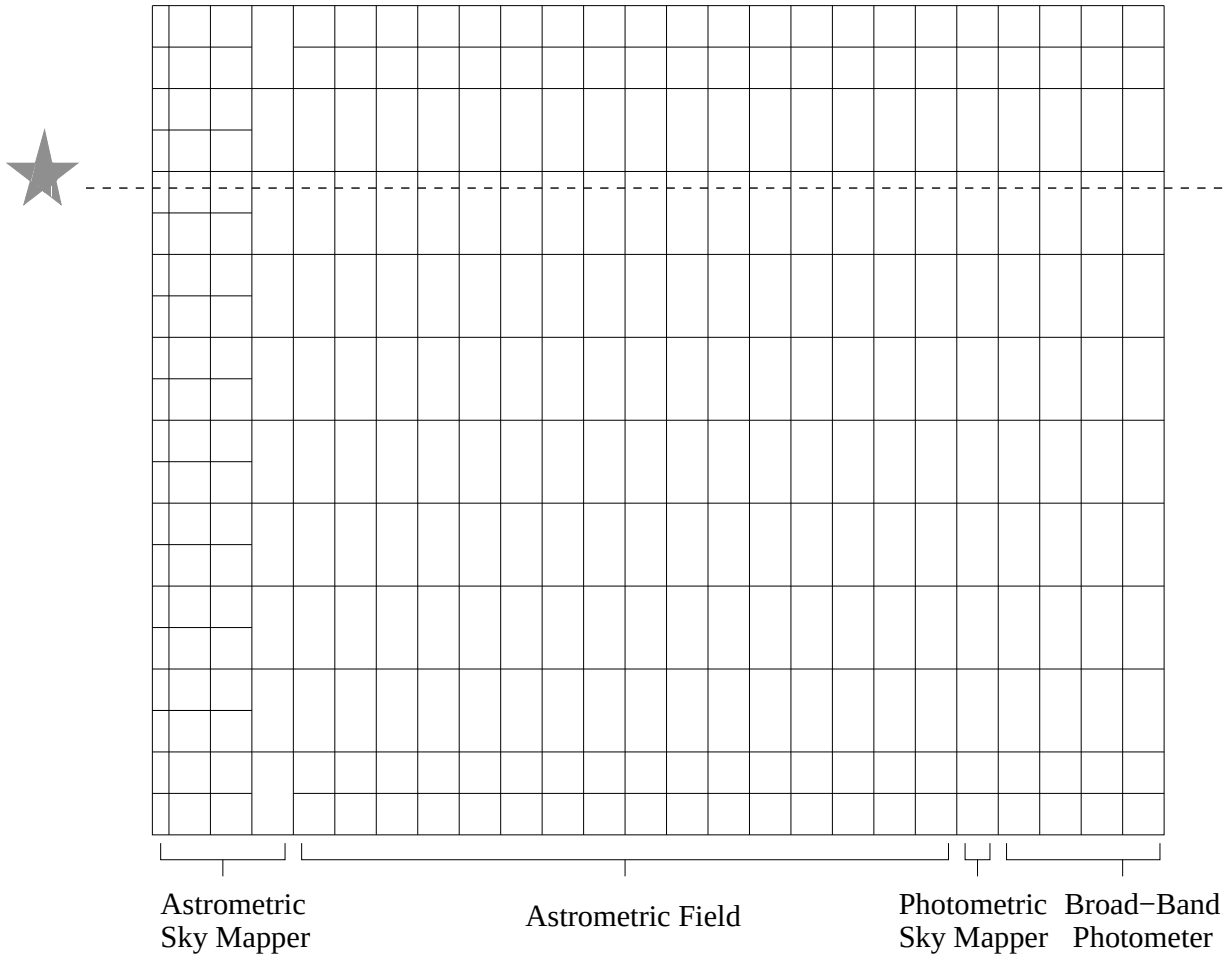
Payload



- Three three-mirror telescopes: two astrometric instruments (Astros) and one spectrometric instrument (Spectro).
- Astros: astrometry, broad-band photometry in G and $UBVRI$-like bands. $Ap = 1.7 \times 0.7$ m^2. Airy Disk of 135×325 mas^2 at $\lambda = 550$ nm. $FOV = 0.80 \times 0.68$ deg^2.
- Spectro: radial velocities and medium-band photometry. $Ap = 0.75 \times 0.70$ m^2. $FOV = 2 \times 1$ deg^2.
- CCDs sensitive from 250 to 1050 nm (G band), with a pixel size of 9×27 μm^2 $= 37.2 \times 111.6$ mas^2.

Focal Plane of Astrometric Instruments

- A mosaic of $\simeq$ 300 CCDs, along which the objects move due to the satellite spinning motion. Charges are shifted along the CCDs at the same speed in order to increase the exposre time.



- Its structure mirrors the adopted observation philosophy, which is to maximize the scientific information per bit transmitted to ground
- ASM: object detection
- AF: astrometry and G-band photometry of detected objects
- PSM: all-sky G-band photometric mapping
- BBP: broad-band ($UBVRI$-like) photometry of detected objects

Performance

- Astrometric, photometric and spectroscopic survey
- All-sky coverage
- A limiting magnitude of $V \simeq 20$
- A complete sample at the limiting magnitude of $\simeq 10^9$ objects (25 000 objects/deg^2)
- High accuracy: 10 μas, 5 mmag and 1 km/s at $V = 15$
- High spatial resolution: down to 0.25 arcsec

Scientific Objectives

- Galactic Astrophysics
- Distance Scale
- Solar System
- Local Group
- Galaxies
- Stellar Astrophyisics
- Fundamental Physics
- Extra-Solar Planets
- Supernovae
- Quasars

Objectives of the Thesis

- GAIA can "naturally" obtain an astrometric and photometric galaxy survey

$$\Downarrow$$

  - Discrimination of point-like objects and diffuse objects
  - Determination of an appropriate CCD binning
  - Development of a technique for the combination of different observations
  - Estimation of the performance
  - Discussion of scientific results

Statistical Model of Galaxies

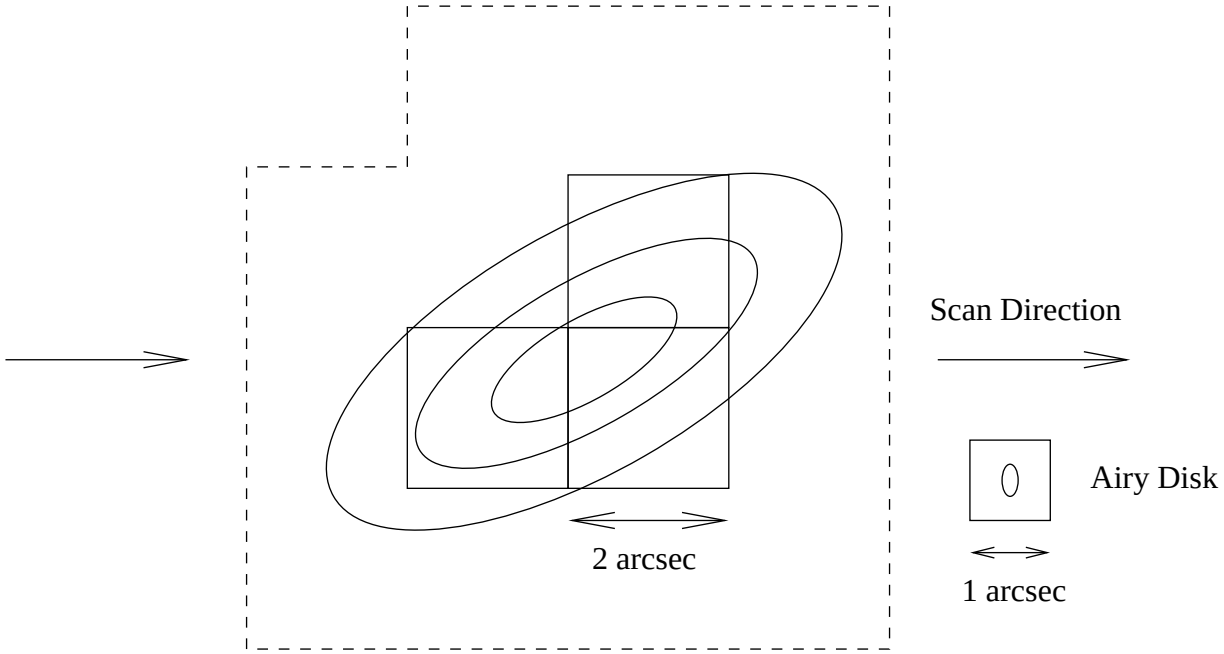
- The model combines observational data with empirical laws describing typical galaxy surface brightness radial profiles. The independent variables are the morphological type (E or D) and the total magnitude in the I band, the outputs are:
  - Differential counts: $N = N(I)$
  - Cumulative counts: $N_c = N_c(I)$
  - Effective radius: $r_e = r_e(I)$
  - Effective surface brightness for E and D: $\Sigma_{E,e} = \Sigma_{E,e}(I)$ e $\Sigma_{D,e} = \Sigma_{D,e}(I)$
  - Surface brightness radial profile for E and D:

$$\Sigma_E(r) = \Sigma_{E,e} \exp\left(-7.6692\left[\left(\frac{r}{r_e}\right)^{1/4} - 1\right]\right)$$

$$\Sigma_D(r) = 0.76931\,\Sigma_{D,e} \exp\left(-7.6692\left[\left(\frac{1.6617\,r}{r_e}\right)^{1/4} - 1\right]\right) + 2.9343\,\Sigma_{D,e} \exp\left(-\frac{1.3945\,r}{r_e}\right)$$

- Model's validity: within 0.2 mag/arcsec^2 up to $\simeq 4\,r_e$

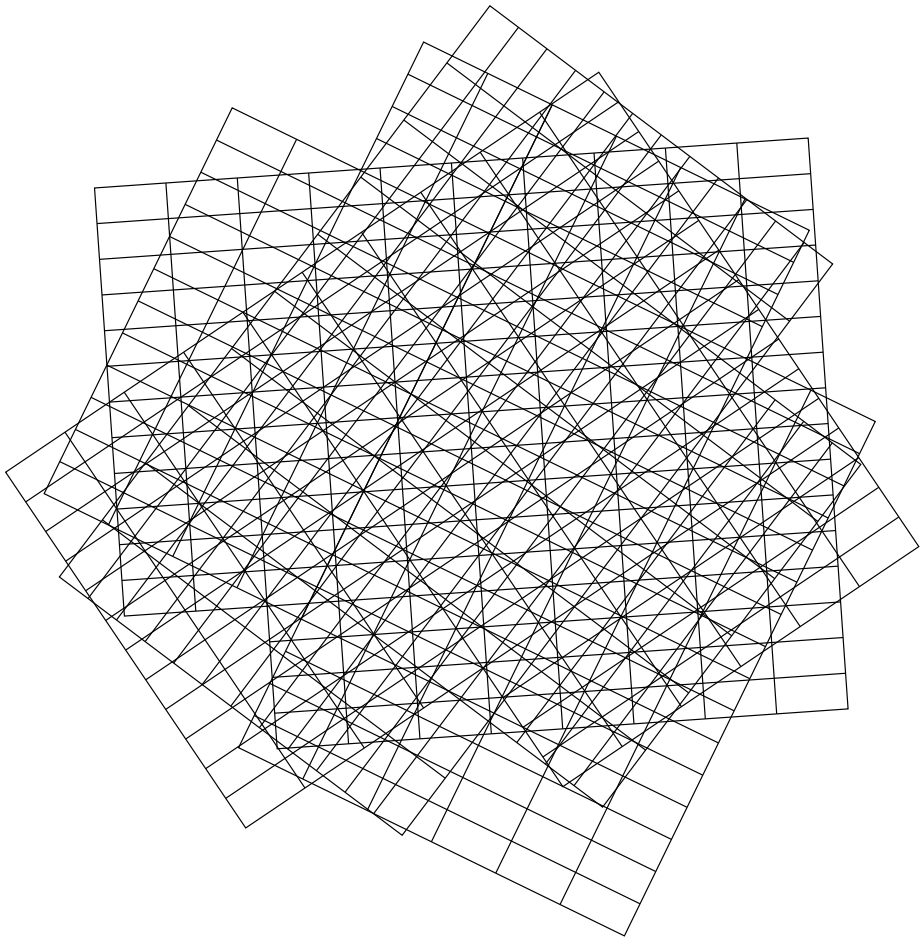
Galaxy Detection



- Galaxies are detected in the ASM as an average surface brightness significantly in excess ($S/N > 4$) with respect to the local sky background within an area of 2×2 arcsec^2.
- Whenever a galaxy is detected, the corresponding sky region and its surroundings are observed in the BBP.

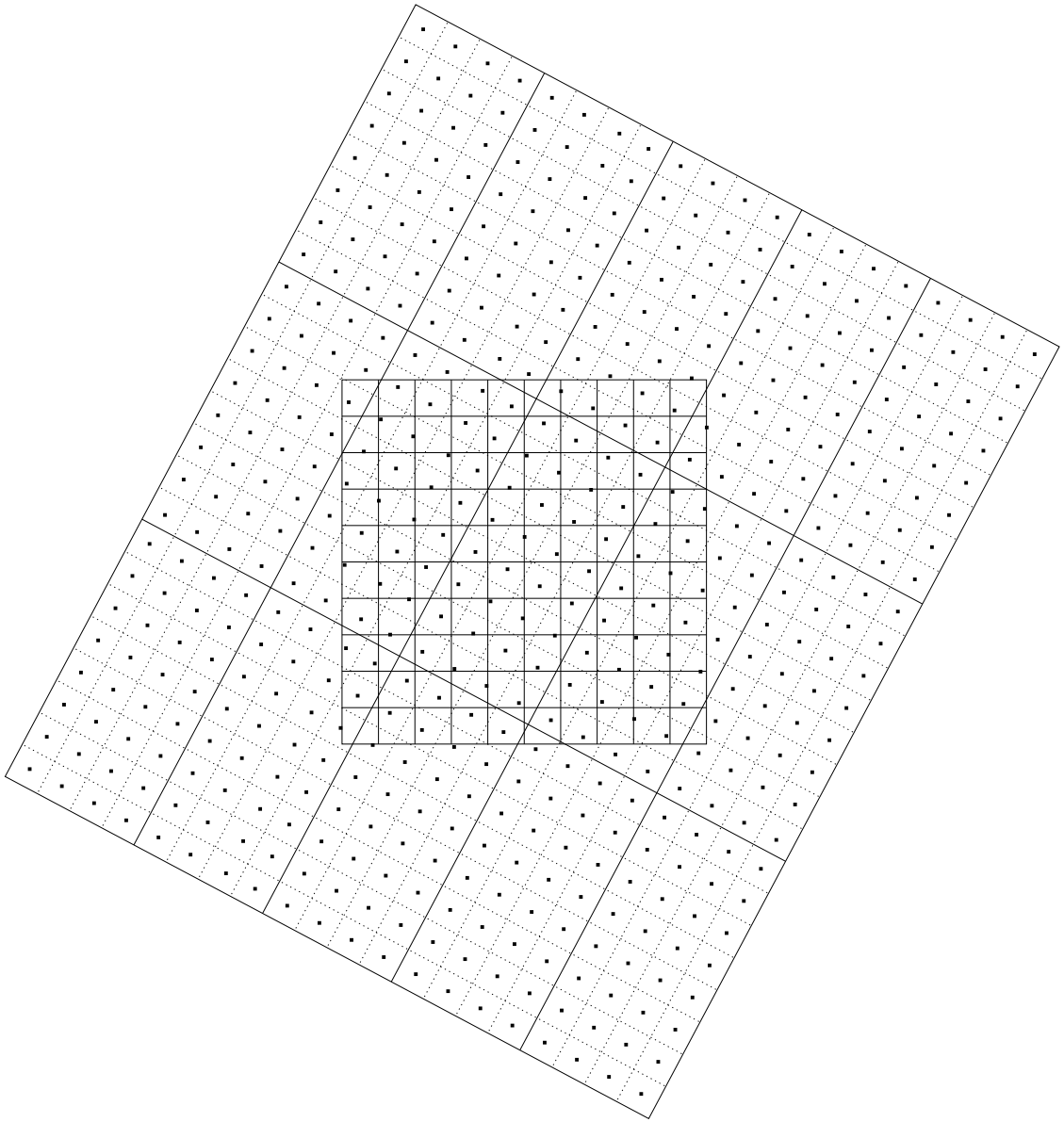
- A galaxy of $I = 17$ would be detected 60% of the times
- $I \leq 17$ and $|b| > 15 \Rightarrow$ at least 3 million galaxies

Galaxy Observation



- The adopted binning determines the level of undersampling, the angular resolution, the accuracy in surface photometry and the required telemetry rate for galaxy observation
- Different observations of the same galaxy are centered and oriented differently

Subpixeling and Rebinning



- The pixels of the image are first divided into a certain number of square subpixels, each containing an equal fraction of the counts of the original pixel
- The counts associated with each subpixel are then assigned to the pixel of the final image containing the subpixel's center
- This procedure preserves the total flux but does not recover the optical resolution which is lost due to undersampling
- The techniques developed to recover the optical resolution from undersampled HST WFPC2 images are not applicable

Simulation and Superposition of Observations

Simulation

HST WFPC2 Image

$\Downarrow$

- Conversion of counts
- Subpixeling
- Rototranslation
- Rebinning
- Convolution with GAIA PSF
- Addition of Poisson noise and RON

$\Downarrow$

GAIA BBP Simulated Observation

Superposition

GAIA BBP Simulated Observation

$\Downarrow$

- Subpixeling
- Counter-rototranslation
- Rebinning

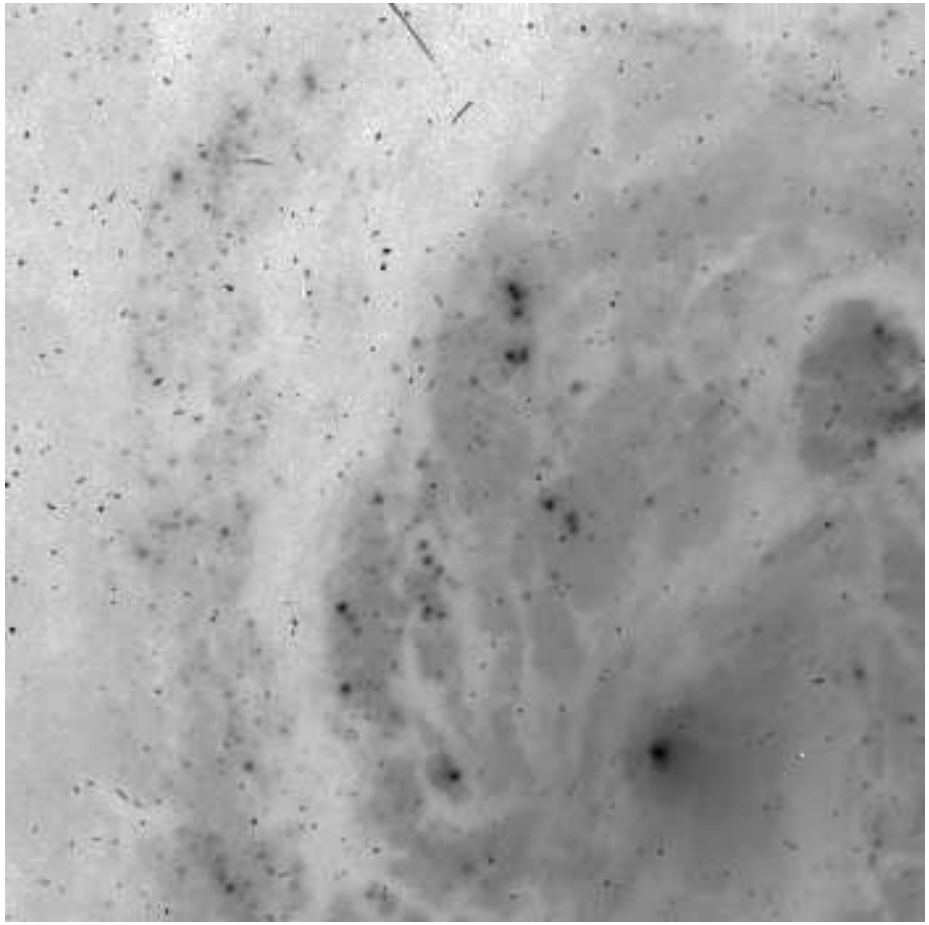
$\Downarrow$

Simulated GAIA BBP Flux Map

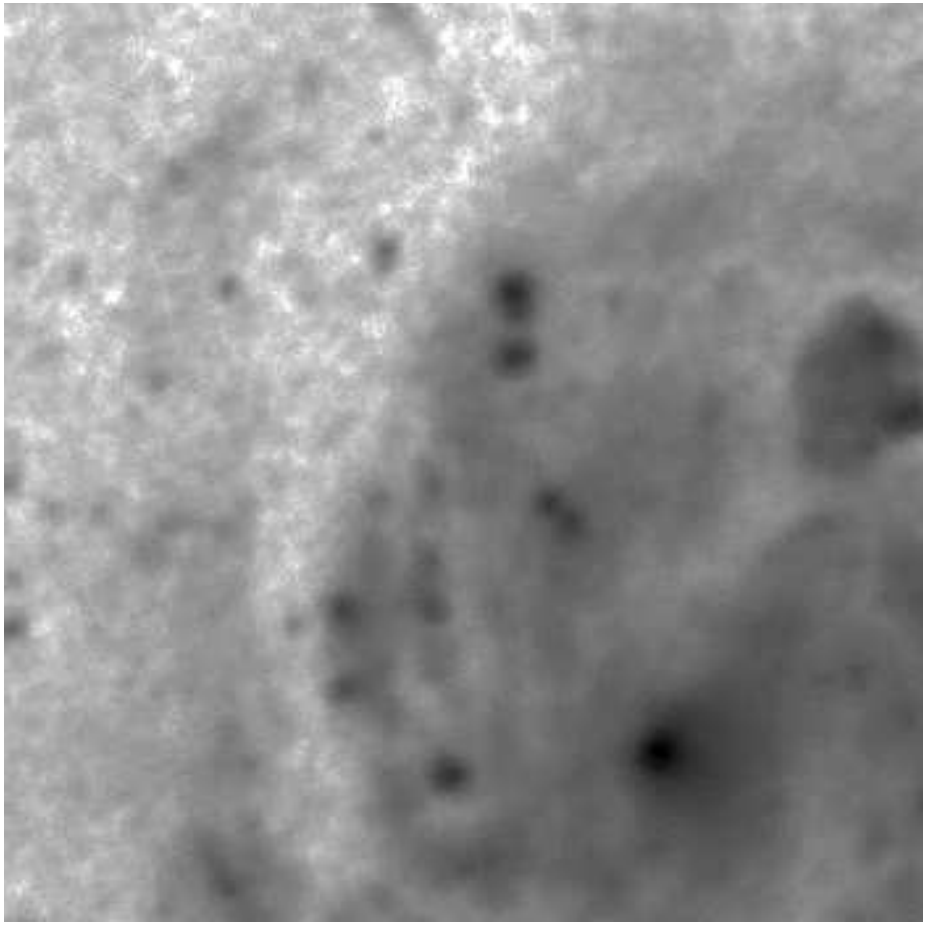
$\Downarrow$

Optimal binning of 6×4 pixel $= 223.2 \times 446.4$ mas^2

Flux Maps: M100



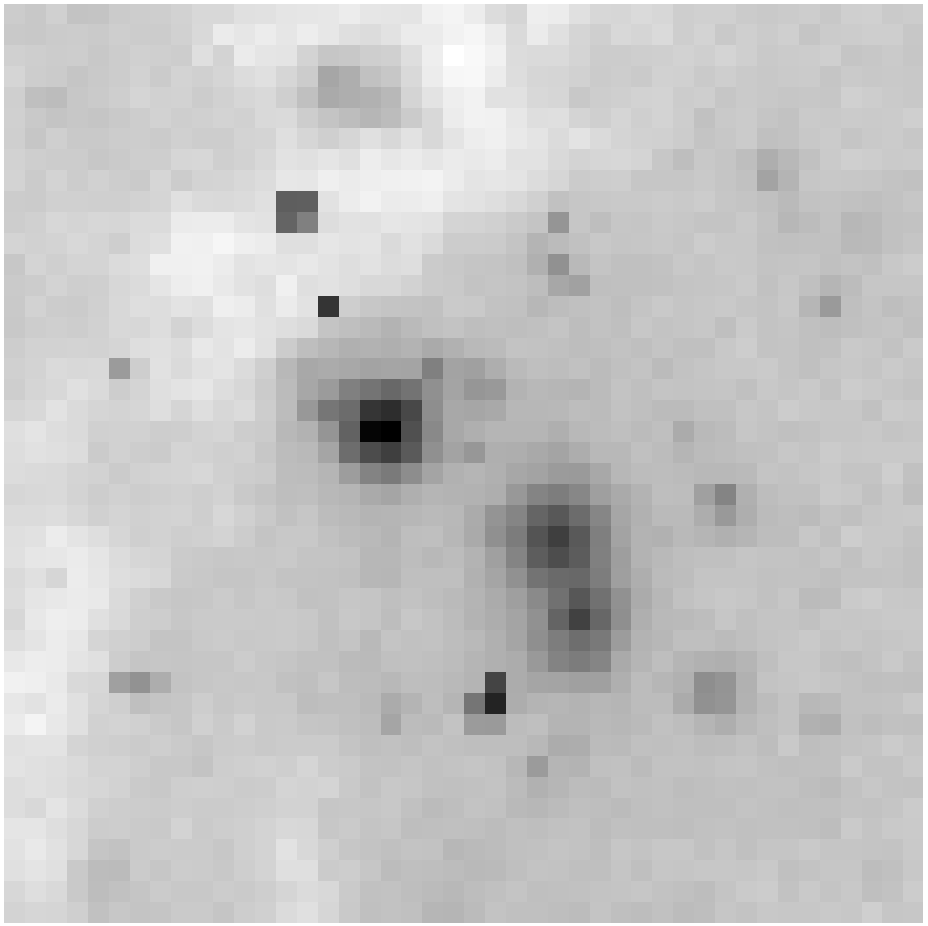
Original Image (HST WFPC2, 900 s)



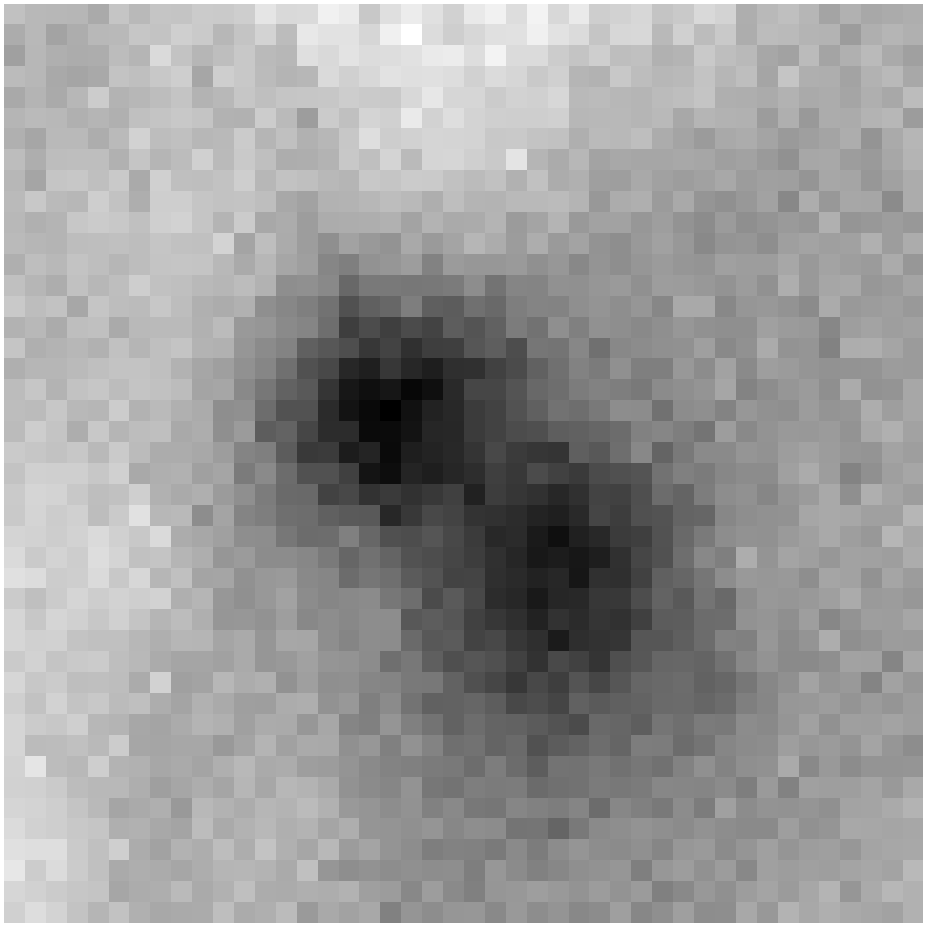
Simulated Flux Map (GAIA BBP, 43.09 s)

- The accuracy in surface photometry is of 0.15 mag/arcsec^2 at $\mu_V = 19.5$ mag/arcsec^2

Angular Resolution of Flux Maps: a detail of M100



Original Image (HST WFPC2, 900 s)



Simulated Flux Map (GAIA BBP, 43.09 s)

- The angular resolution is better than 0.4 arcsec

Conclusions: Performance

- An astrometric and photometric galaxy survey
- A limiting magnitude of $I \simeq 17$, corresponding to $z \simeq 0.1$ or $d \simeq 400$ Mpc
- A coverage of at least 75% of the sky down to low Galactic latitudes
- A sample of at least 3 million galaxies
- Multi-color observations (4-5 $UBVRI$-like bands)
- Multi-epoch observations (on average 85 observations in 5 years)
- An angular resolution better than 0.4 arcsec
- An accuracy in surface photometry of 0.15 mag/arcsec^2 at $\mu_V = 19.5$ mag/arcsec^2.

Conclusions: Scientific Results

- Spatial Distribution
  - Large-scale structure in the Local Universe
  - Peculiar motions in the Local Group
  - Detection of astrometric "jitter" in galactic nuclei
- Surface Photometry
  - Bright galaxies: detailed analysis of morphology
  - Faint galaxies: statistical analysis of photometric structure in the inner regions
  - Mapping of star-forming regions and dust lanes
  - Detection of photometric variability in galactic nuclei