Gaia I: the Mission
-
the adventure begins

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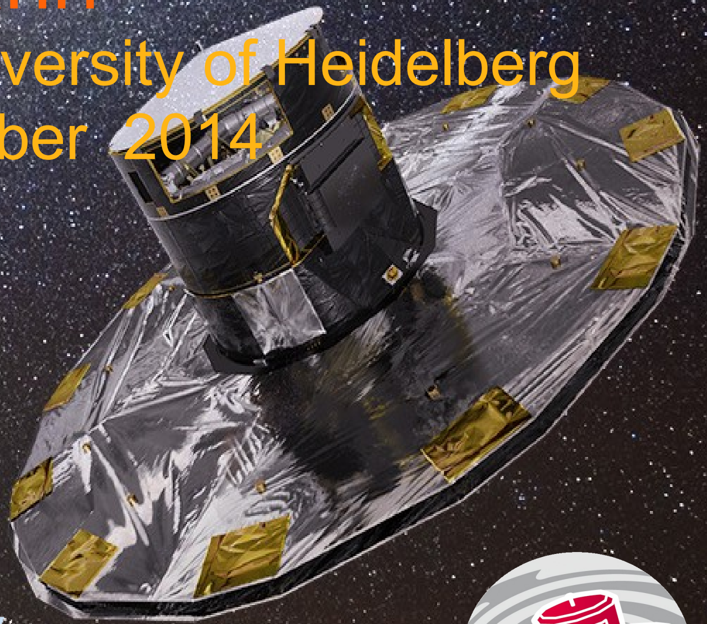
Santiago, 30th September 2014



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Gaia – the promise

- 1 billion stars to 20^{th} magnitude, 1% of MW stars
- Full 5 parameter astrometric data for 10^9 stars
  - Between 10 and 300 μas precision for parallaxes, positions and proper motions!
- Multi colour (spectro)photometry of 10^9 stars
- High resol. spectroscopy for 10^8 stars to 17^{th} mag
  - Radial velocities, abundances, rotation velocities for the brighter objects.

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Gaia – the promise

- Calibration of the cosmic distance ladder
- Kinematics of the components of the Milky Way and its satellites
- Solar system objects (NEOs and PHOs)
- Fundamental physics (gravitational constant)
- Kinematics/Dynamics of star clusters
- Transient objects
- positions of 1 million QSOs/AGNs

Gaia – the promise

- Gaia will revolutionise our understanding of the Galaxy and galaxies in general!
- Enhanced by follow up studies (Gaia ESO Survey) and existing large surveys (SDSS, PanSTARRS, RAVE, 2MASS, MUSYC), Gaia data will even give more insights
- For astrometry of faint objects (Brown & White Dwarfs, M-stars), Gaia will provide an excellent reference frame
-

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Gaia – the promise

Gaia vs. Hipparcos:

Gaia: no input list, all objects included, Hipparcos: Input list for objects <7.3 mag

Stellar distances to	10 %:	150 million (HIP: 21000)
	1 %:	20 million (HIP: 100 ?)
	0.1 %:	1 million (HIP: none)
Variable stars:		50 million (HIP: 8000)
Astrometric binaries:		100 million (HIP: 3000)
with orbits:		100 000 (HIP: 235)

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Gaia – the promise

Gaia vs. today

Direct stellar masses to 1%: > 10 000 (up to now a few dozen ?)

Quasars, galaxies: 500 000, a few dozen million

White dwarfs: 200 000 (up to now 2 000)

Brown dwarfs: 50 000 ? (up to now a few dozen ?)

Planetary systems: 50 000 (up to now 1500 or so)

Supernovae: 10 000 (up to now a few thousand)

Minor planets: 500 000 ? (up to now 200 000)

General relativity to 10^{-6} ? (up to now 50 10-6, or 10 10-6)

Complete stellar counts, precise stellar counts, all-sky inventory

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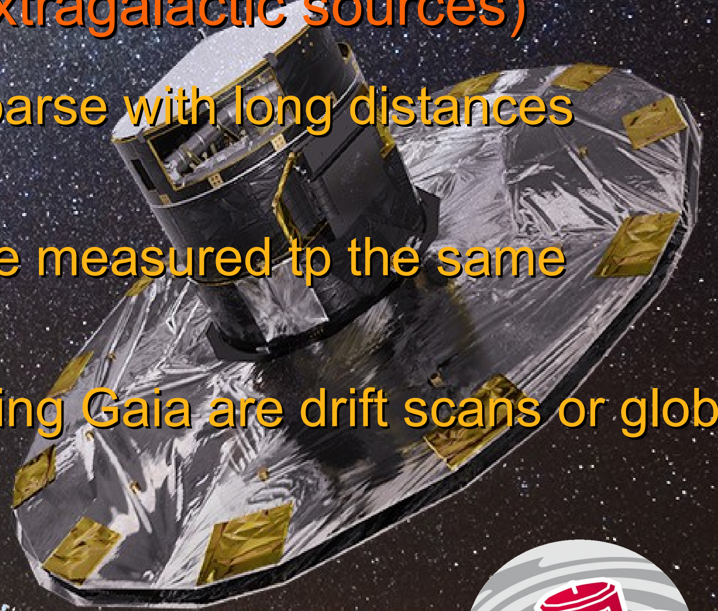
Global (space) astrometry (in a nutshell)

- Small field astrometry: derived coordinates are hinged into a reference frame defined by a reference catalogue and the common objects of Data and catalogue
  - The absolute positions depend on the quality of the reference catalogue
- Global astrometry: Full sky astrometry is fixed to the sources defining the actual reference frame (today mostly extragalactic sources)
  - These official defining sources are quite sparse with long distances inbetween them
  - Large angles between objects must also be measured tp the same accuracy/precision as small angles
  - Most global astrometric enterprises, including Gaia are drift scans or global mosaics



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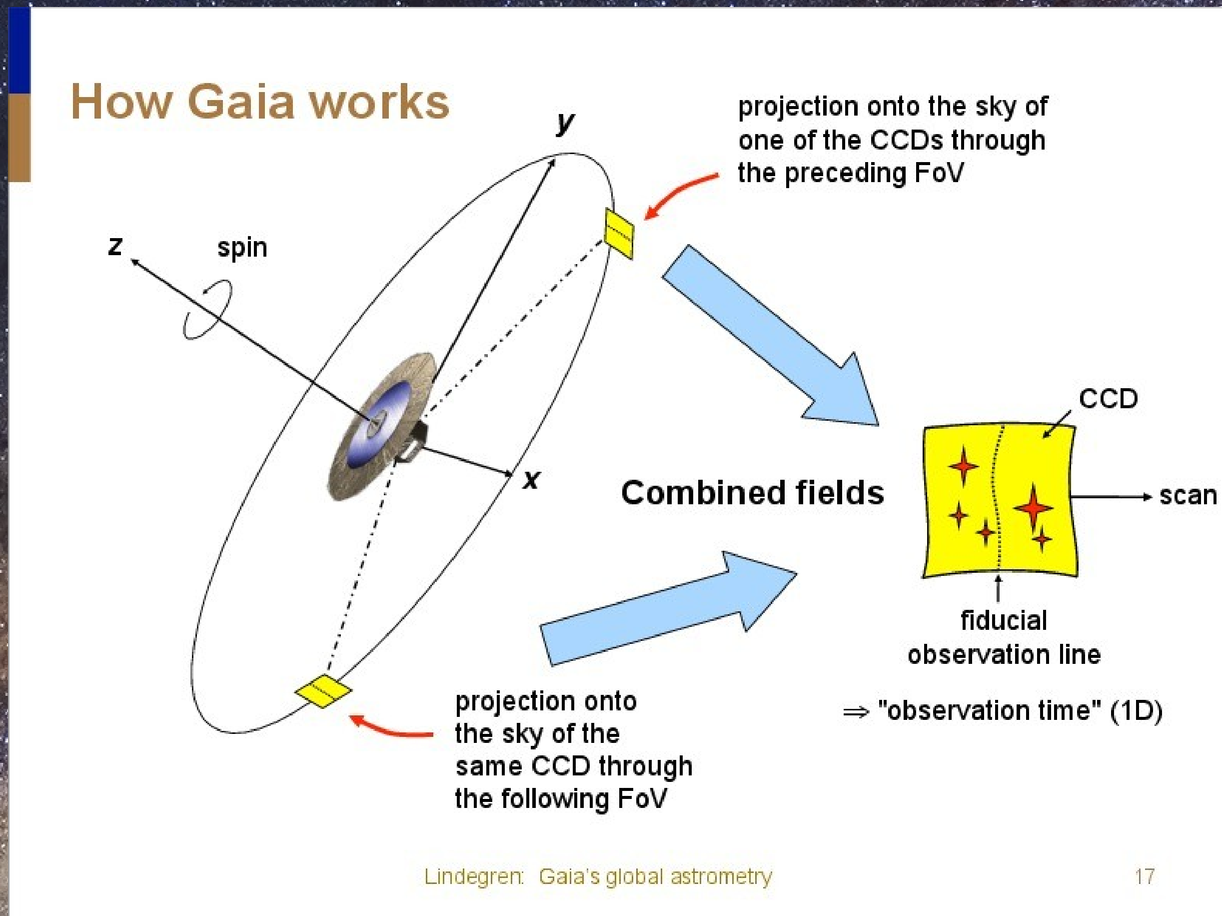
The concept of Gaia

- Gaia has 2 apertures looking 106.5° apart:
  - Ensures measurements of both small angles (interfield), and large angles (field 1 vs. field 2)
  - Allows absolute astrometry
  - Field 2 follows field 1 after 1h46 as the satellite orbits
  - Angle between the fields (“Basic Angle” must be highly stable and its size very well known (specs: 4muas, 7muas noise)
  - BA is monitored by an interferometric device, the BAM
  - Angle of 106.5° has been chosen (apart from technical reasons) to aoid as much aliasing as possible, i.e. being as far away from small fractions of a full circle (180°, 90°, 60°, 120°, 45°, etc.)

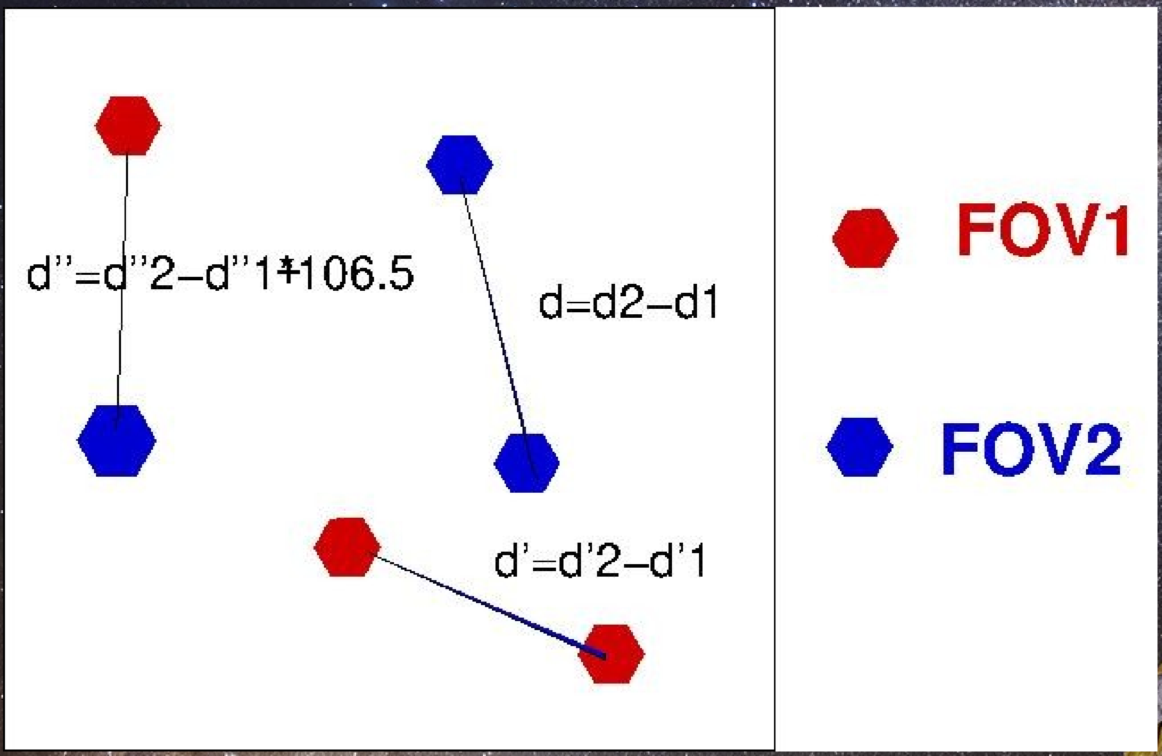
The concept of Gaia



http://www.astro.unipd.it/ScuolaNazionale2010/Lessons/Lindegren.pdf

The concept of Gaia

- On the astrometric chips:



VEEEERY simplified View, no aberration, no Physical effects, no motions, only positions

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The concept of Gaia

- The measuring concept of Gaia allows:
  - A self-contained distortion-free global astrometry
  - Absolute parallaxes
  - Adverse effects, such as aberration affect spacecraft measurments (Earth is also a spacecraft :-))
  - At all times the state of the spacecraft needs to be known (i.e. motions, attitudes, state vector, etc. and factored into the astrometric solution
  - Significant effort necessary to record these quantities (e.g. for the state vector, GBOT was implemented)
  - For a good overview of the concepts behind Gaia, please refer to:

http.◁◁www▷astro▷unipd▷it◁ScuolaNazionale2010◁Lessons◁Lindegren▷pdf

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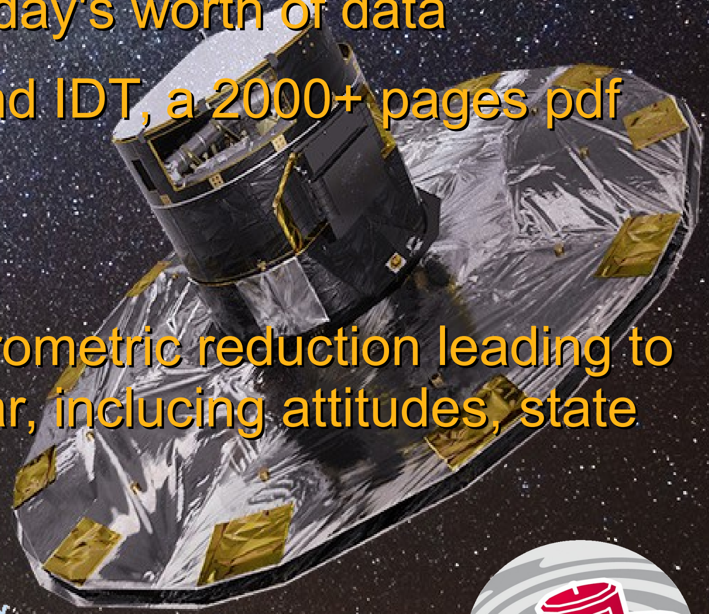
Reduction strategies

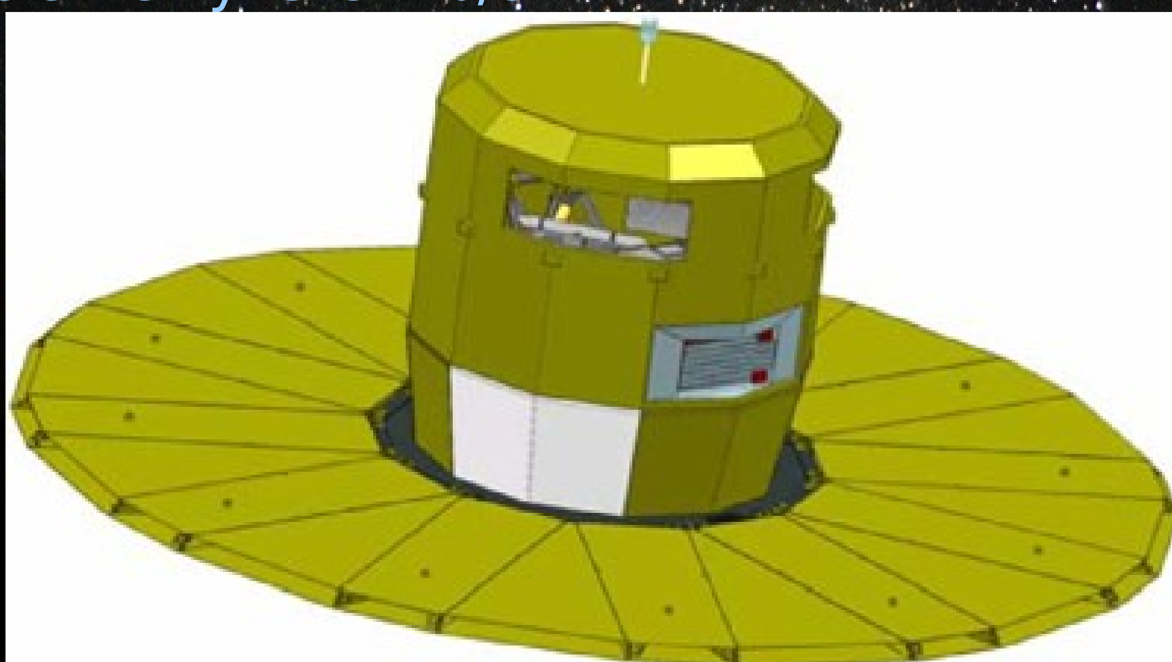
- Daily:
  - Onboard: stamps (windows, size depending on magnitude) with source data get cut out for every detected source an sent down to Earth
  - Initial Data Treatment “reduces” the data, extracts the sources' coordinates, etc.
  - ODAS: One day astrometric solution of a day's worth of data
  - First look monitors the results of ODAS and IDT, a 2000+ pages pdf document is produced daily!
- A few times during the mission:
  - AGIS, the global iterative solution, full astrometric reduction leading to data releases, including all data taken sofar, inclucing attitudes, state vector, etc.

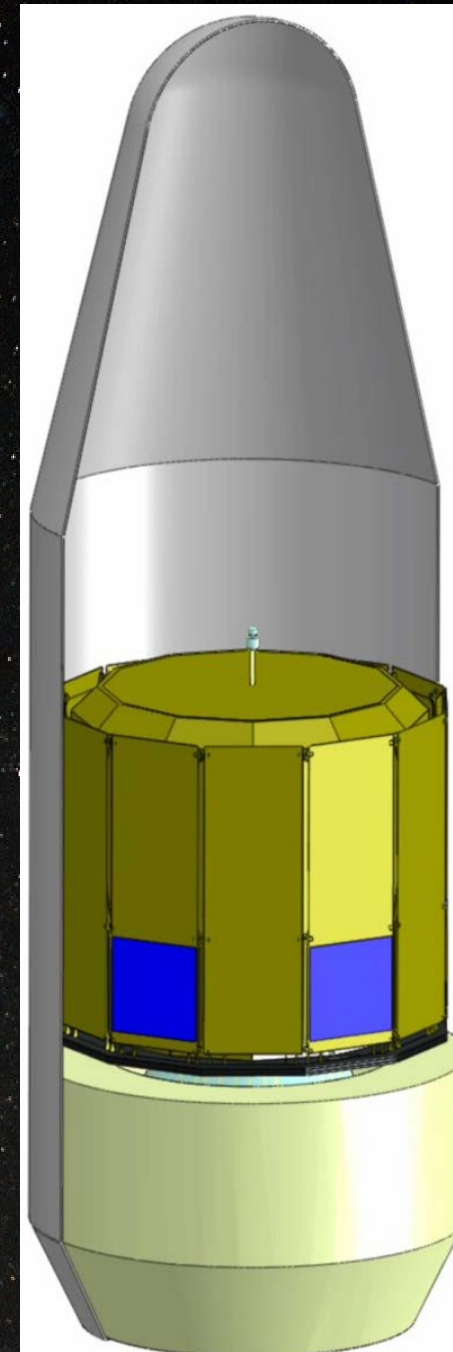


Gaia: the spacecraft

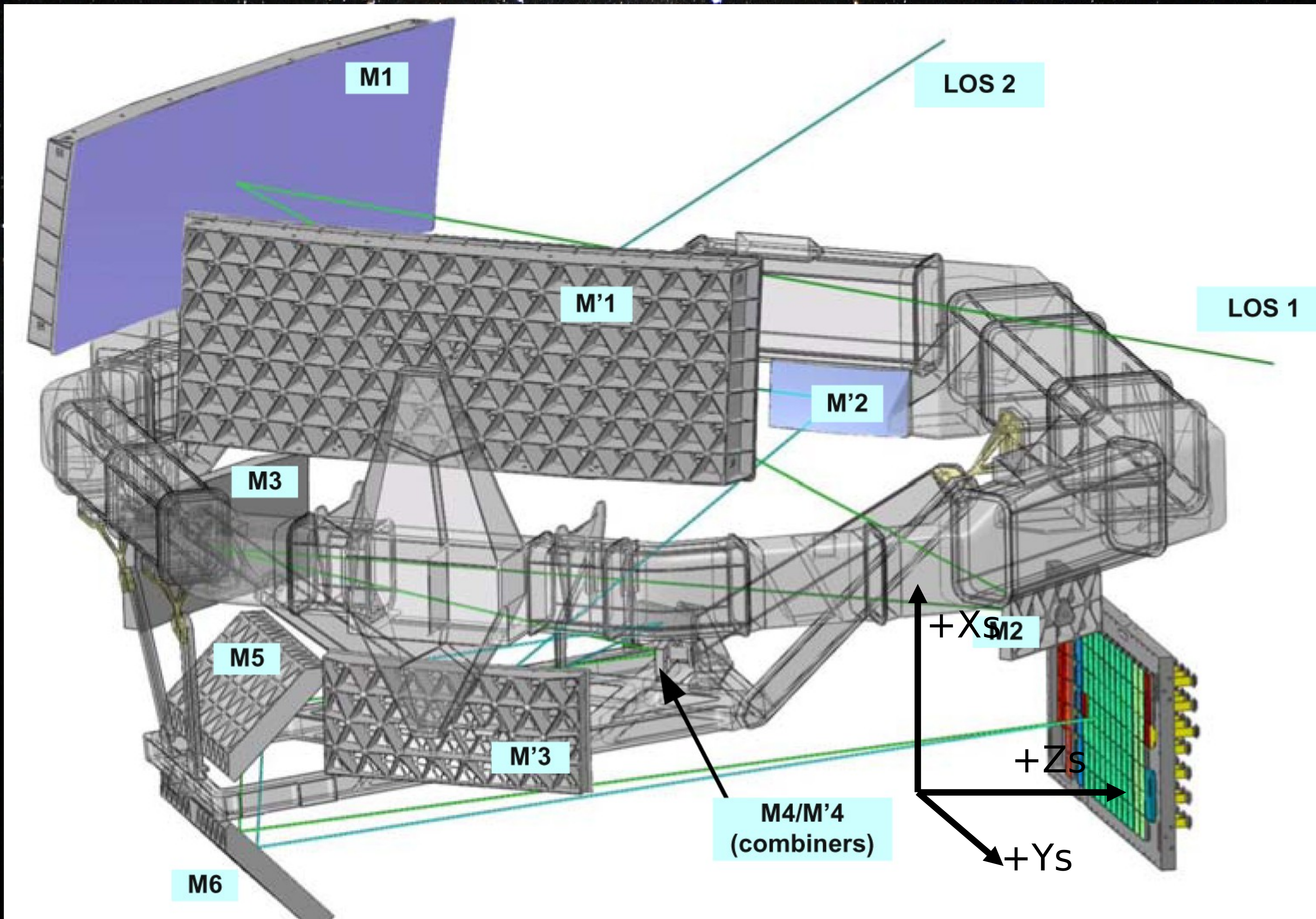
Some technical data:

Diameter: 3 m / 11 m
Height: 3 m
Mass: 1.2 bzw. 1.4 to
Power: 600 plus 500 W
Telemetry: 3-8 Mb/s

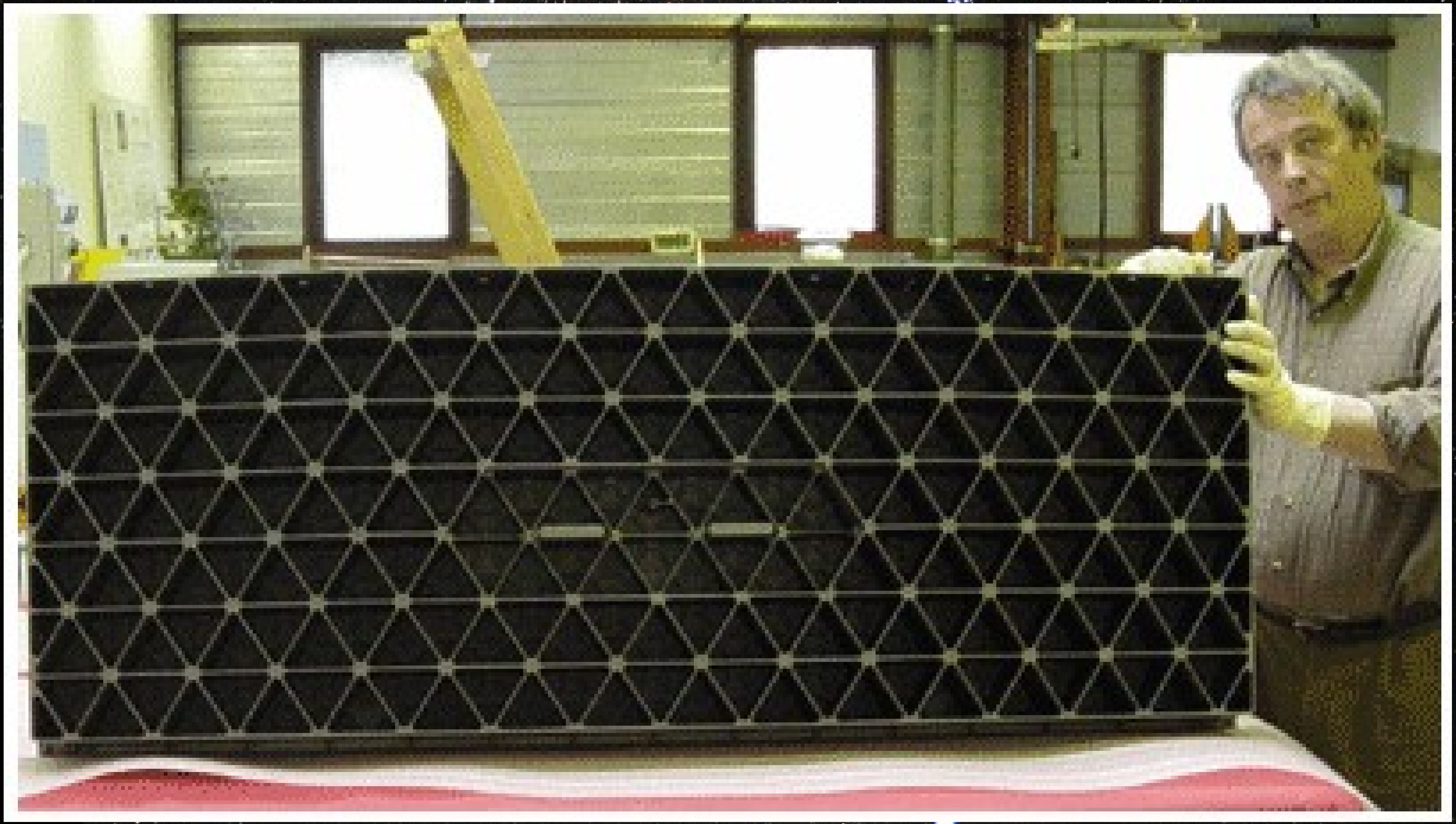




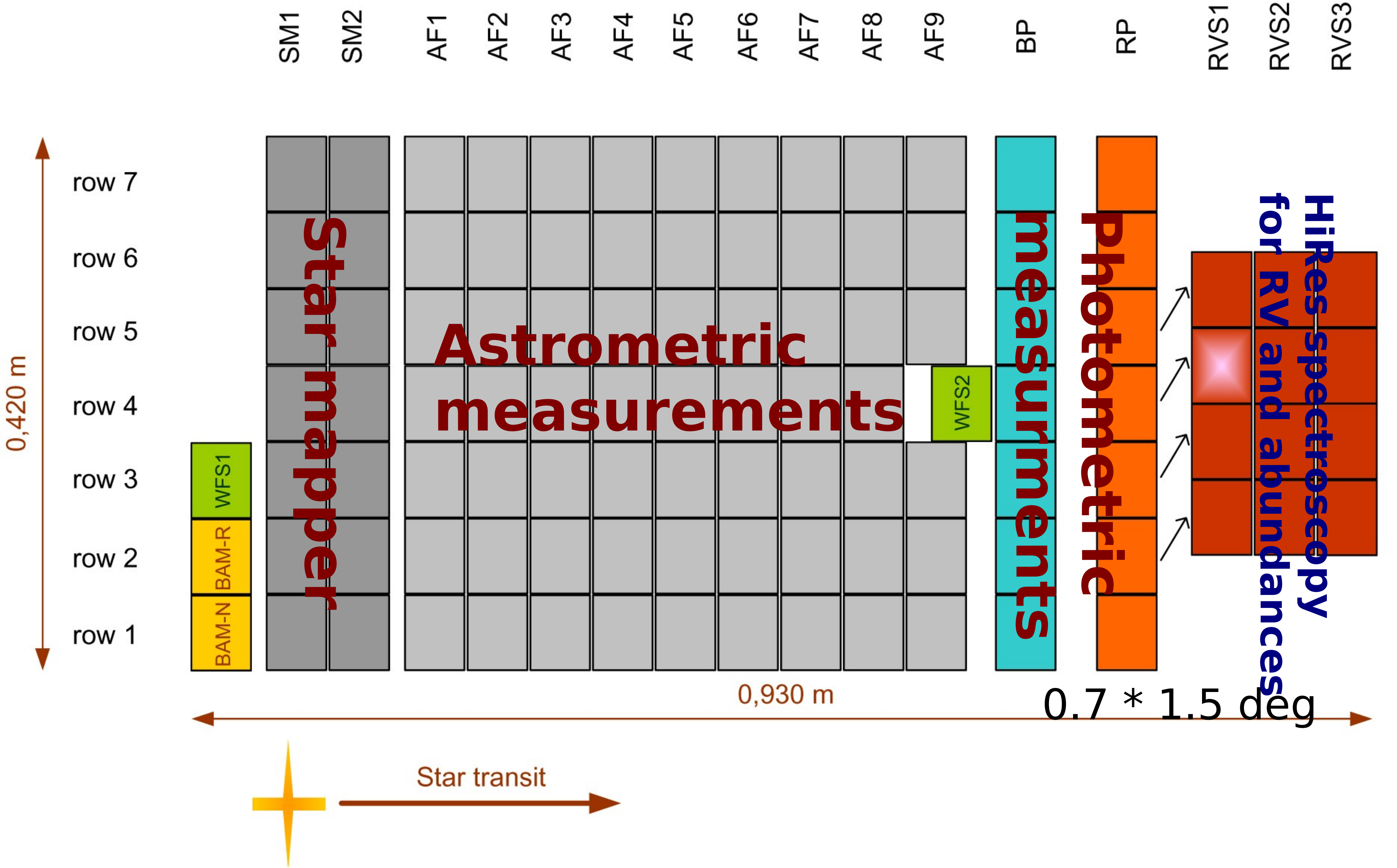
Gaia: the optical assembly



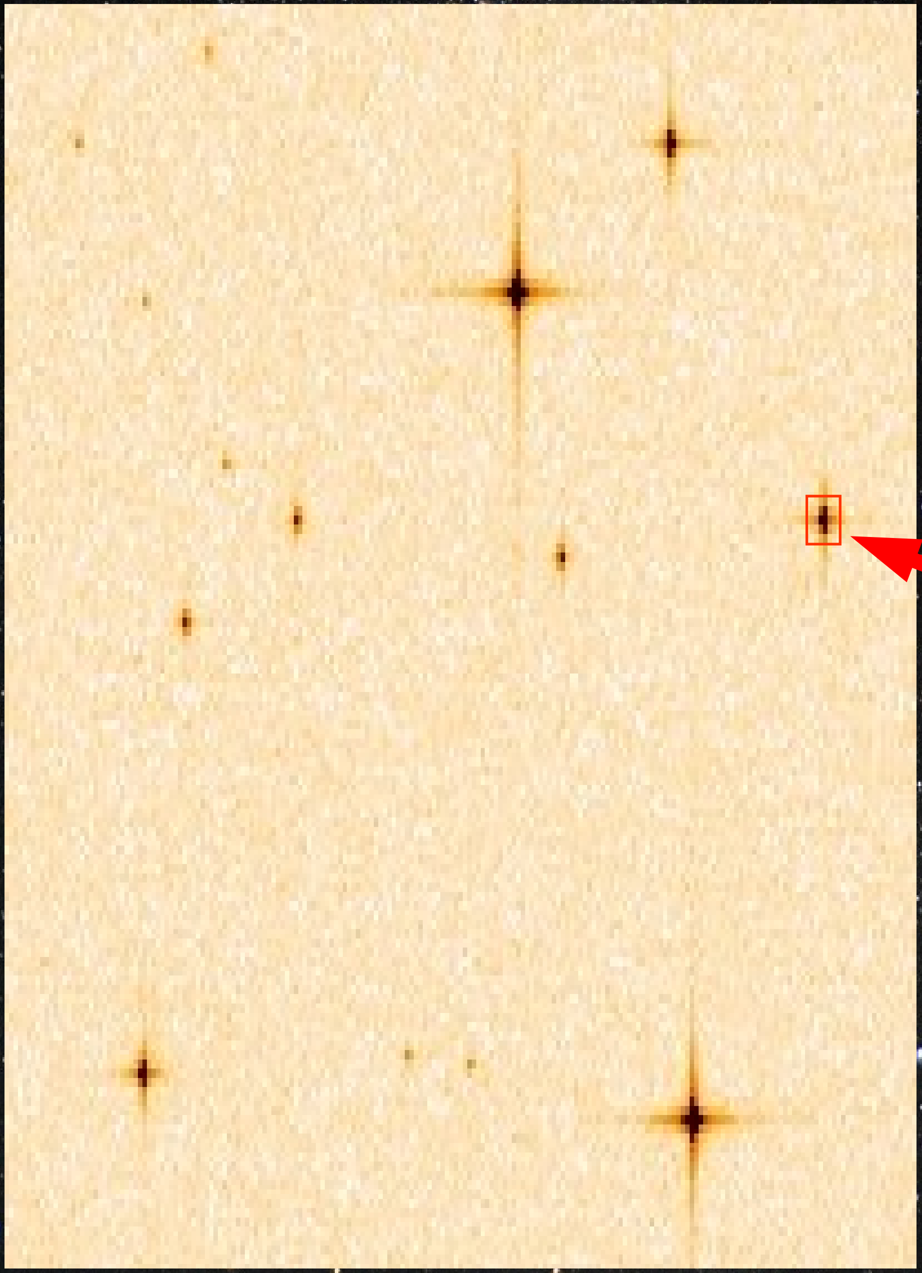
Gaia: one of the main mirrors



Gaia: the focal plane

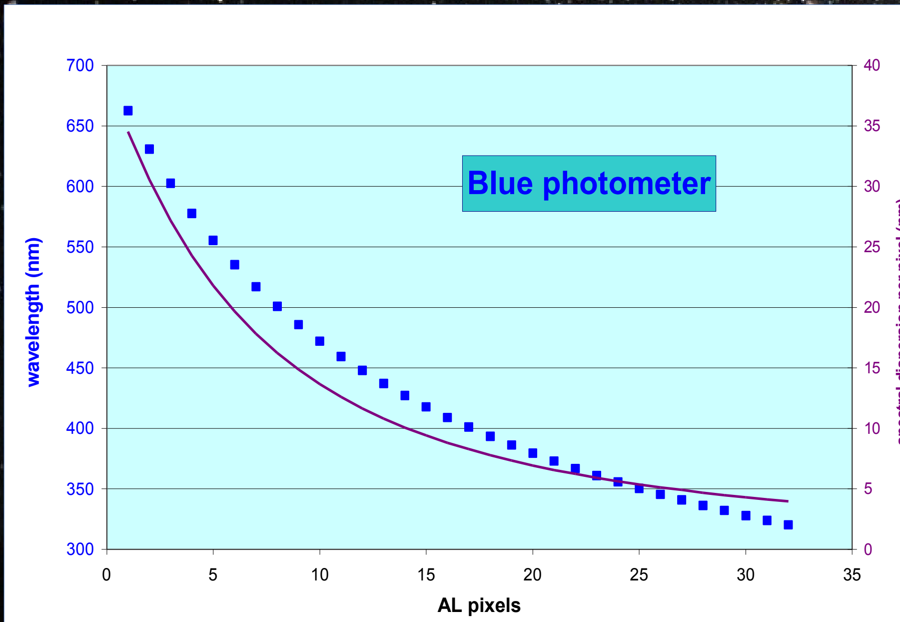


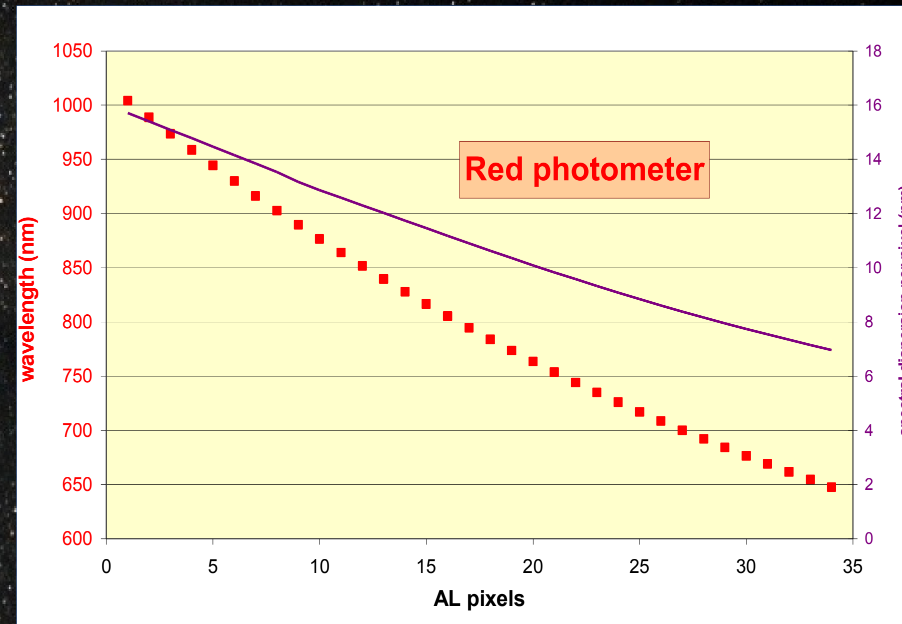
Gaia: Astrometric images

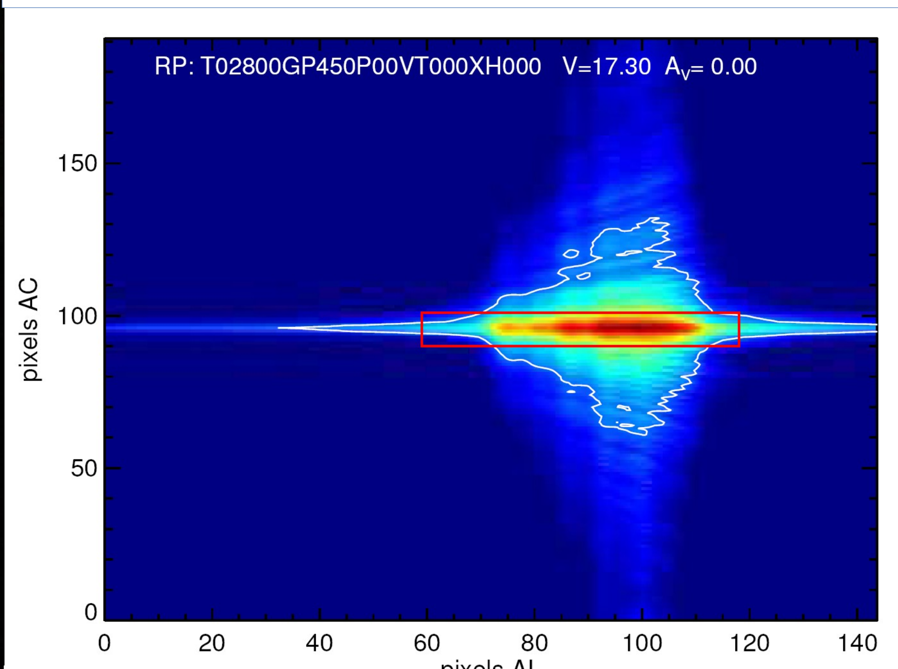


Red box: "window" = data sent to ground (for each detected and confirmed image)

Gaia: Photometry Measurement Concept



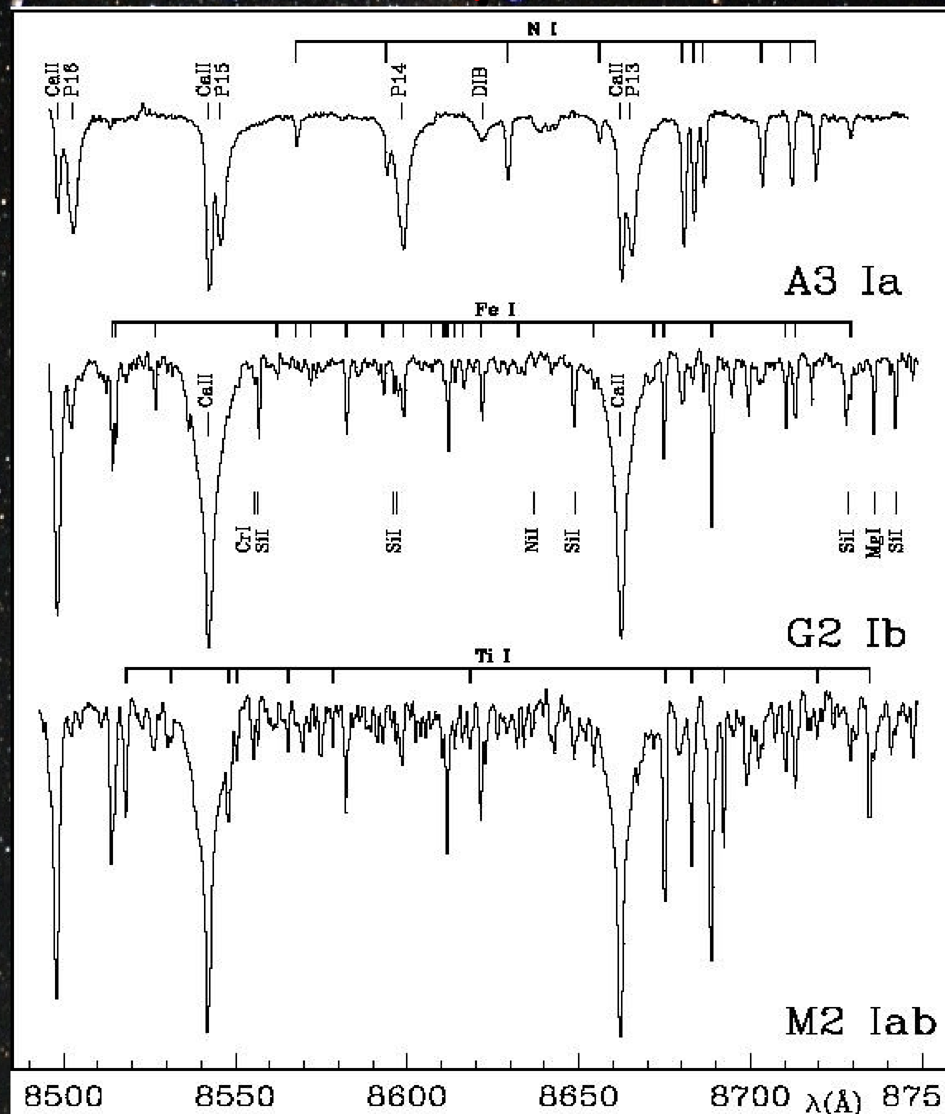




Figu

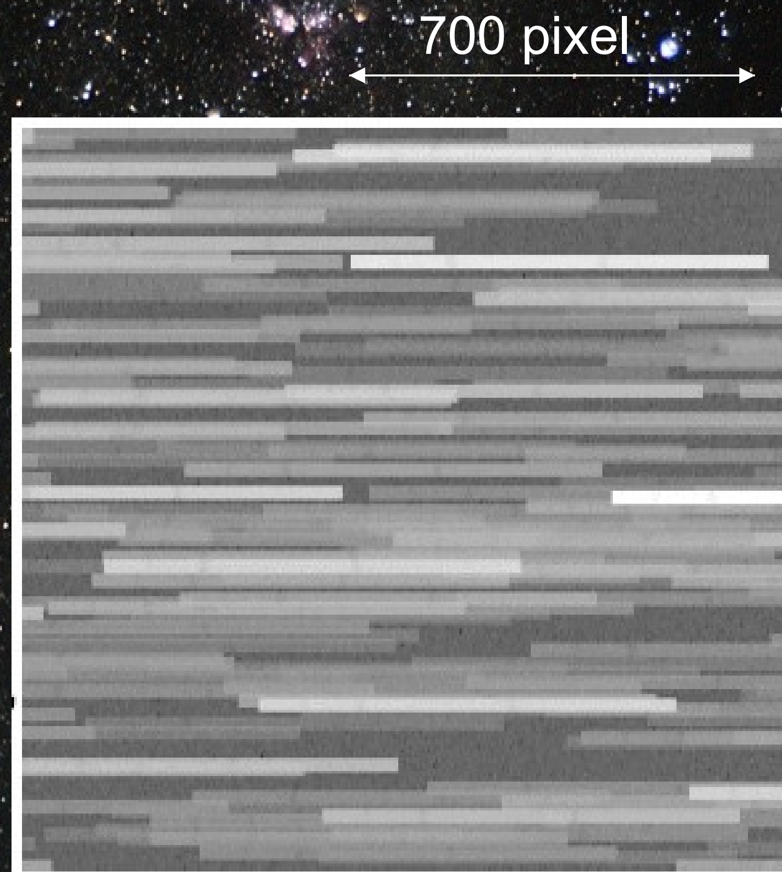
RP spectrum of M dwarf (V=17.3)
Red box: data sent to ground
White contour: sky-background level
Colour coding: signal intensity

Ca II spectra



Effect of temperature: A to M stars

RVS spectra in a dense stellar field (schematic):

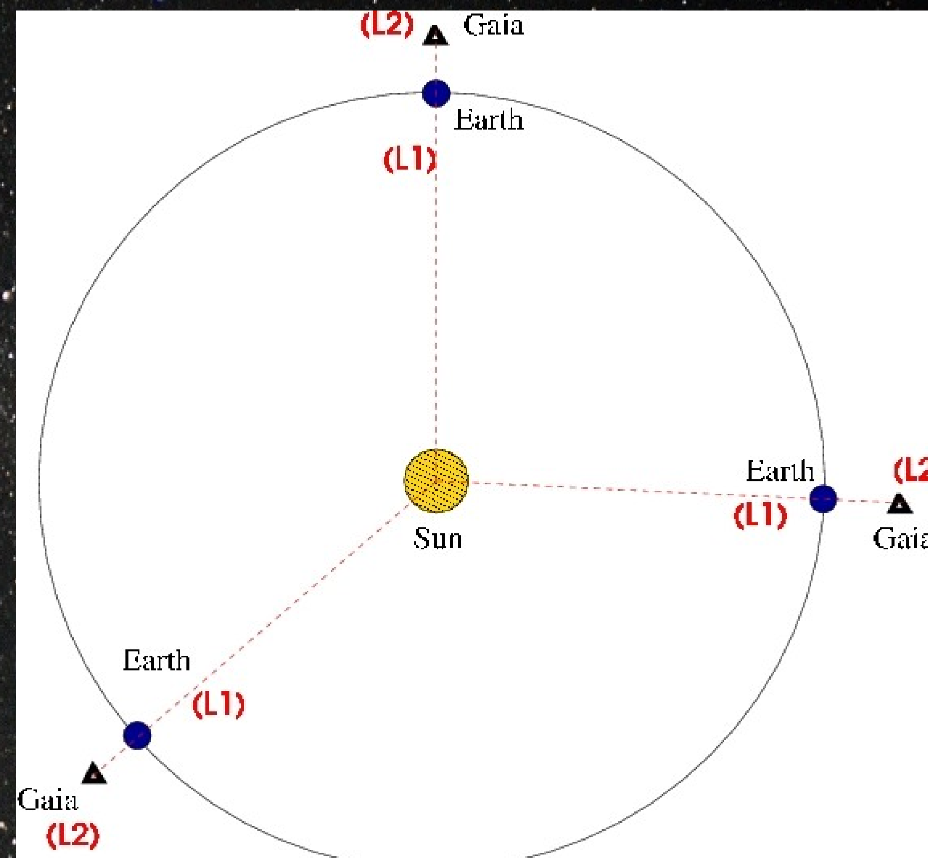


Scan direction →

Gaia's Position near Earth-Sun Lagrange Point L2

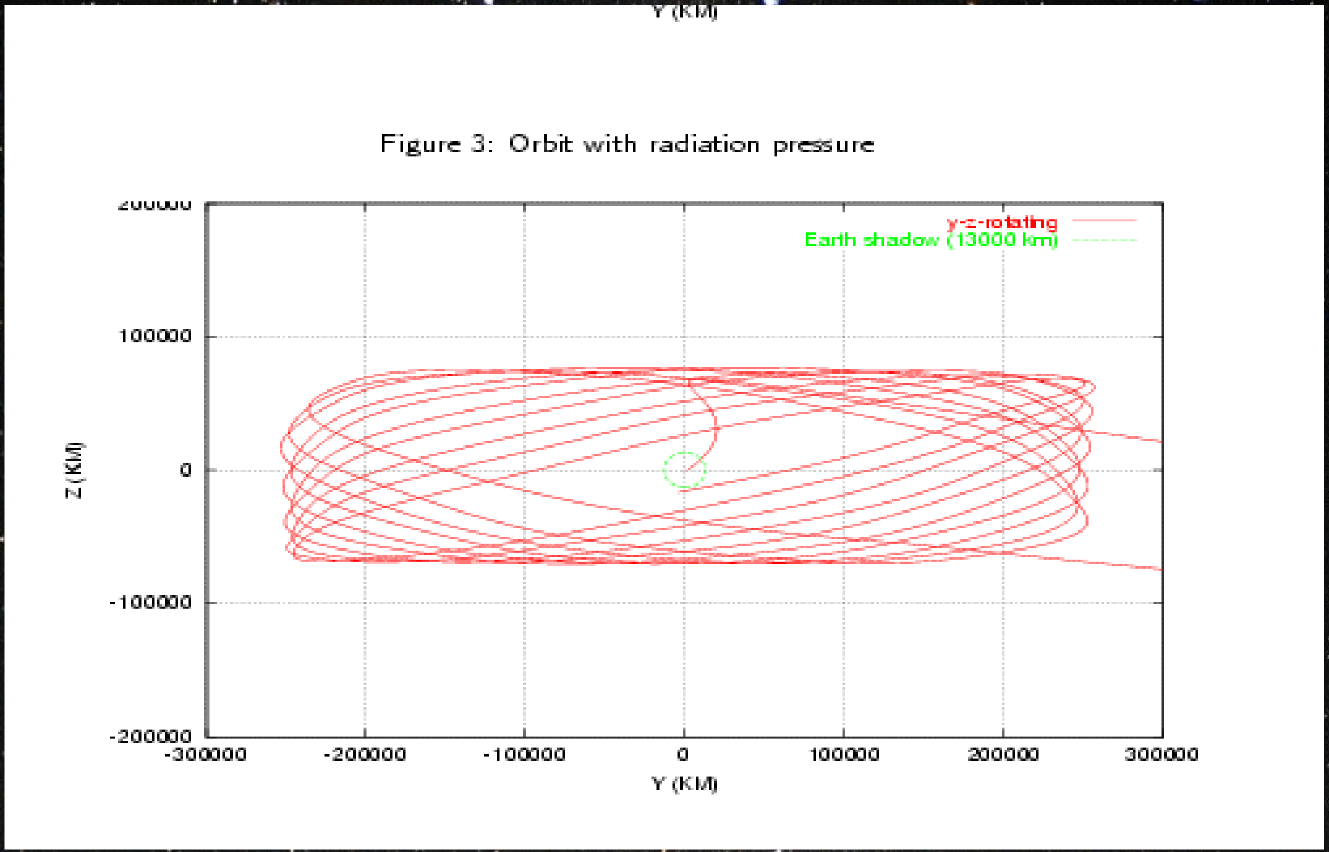
(True distance relation)

Not exactly in L2, because permanent total eclipse there !



Choose an orbit near L2 which
- **avoids the Earth‘s shadow**
- **needs only minor orbital manoevering**

Gaia's orbit around the L2 Lagrangian point



- Orbit actually unstable, 6 monthly corrective boosts in the order of mm/s necessary
- The orbit needs to be known to 150 m in position and 2.5 mm in velocity!
- Satellite needs to be monitored using tracking station <u>*and*</u> optical telescopes (***G***round ***B***ased ***O***ptical ***T***racking)

Sky Scanning Principle

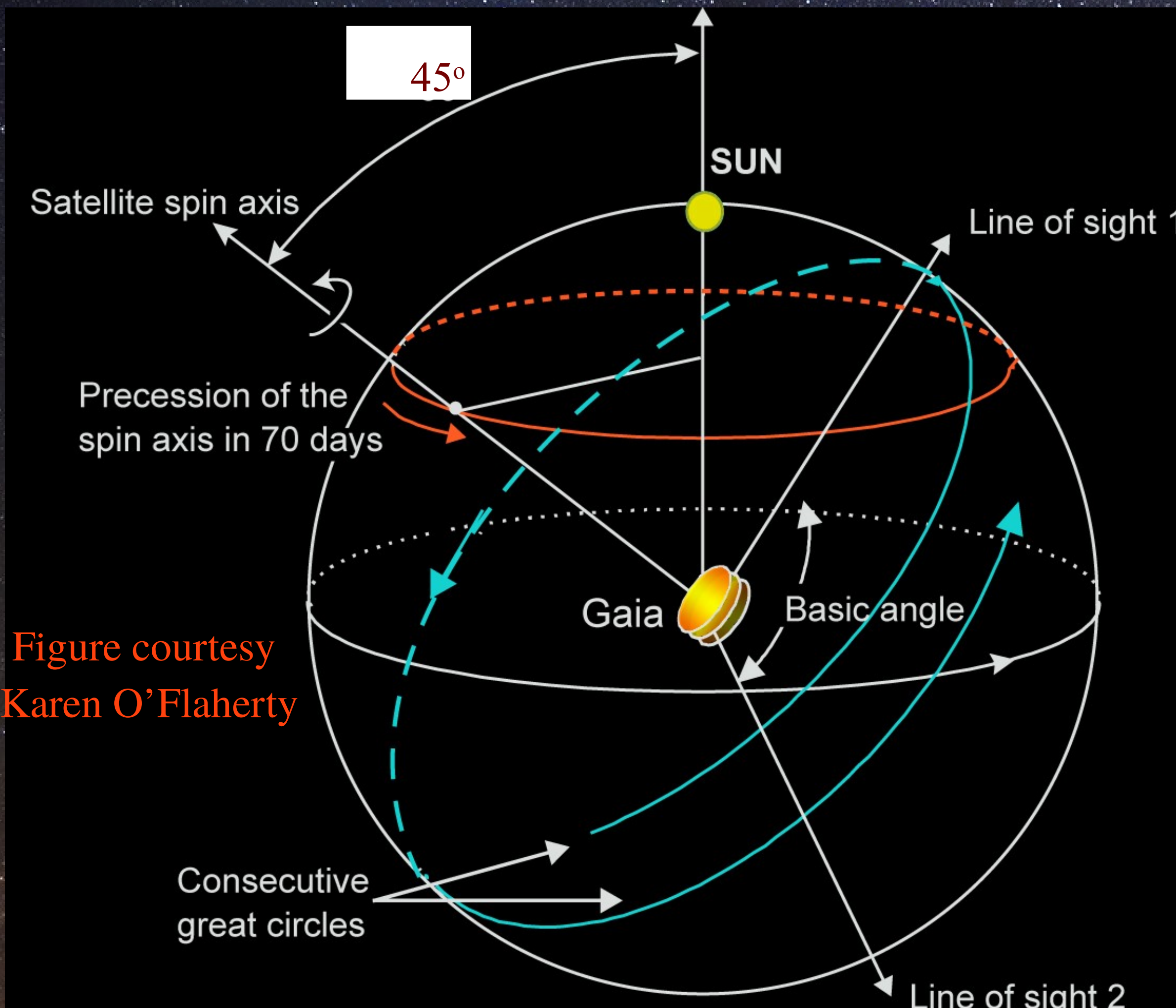
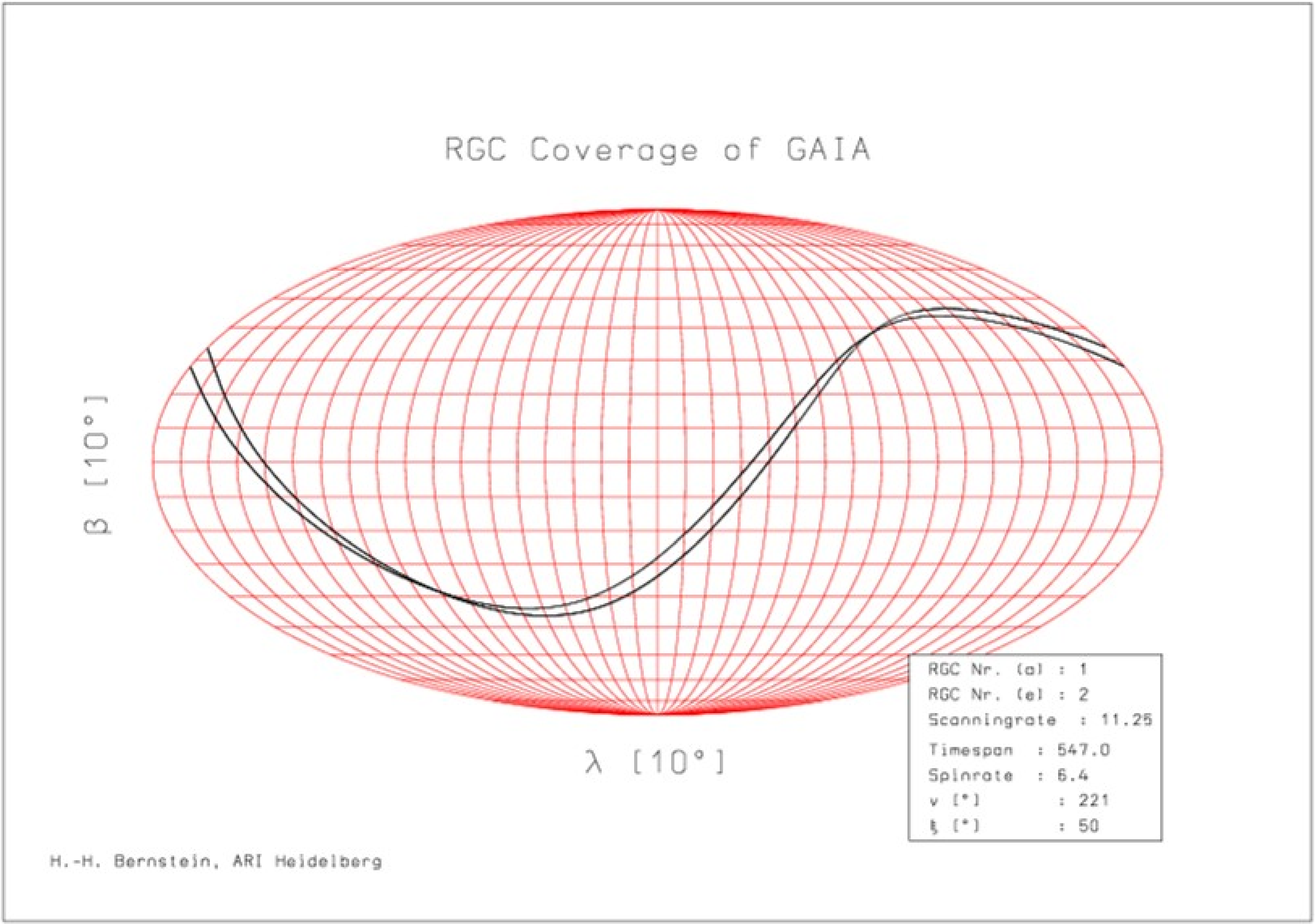
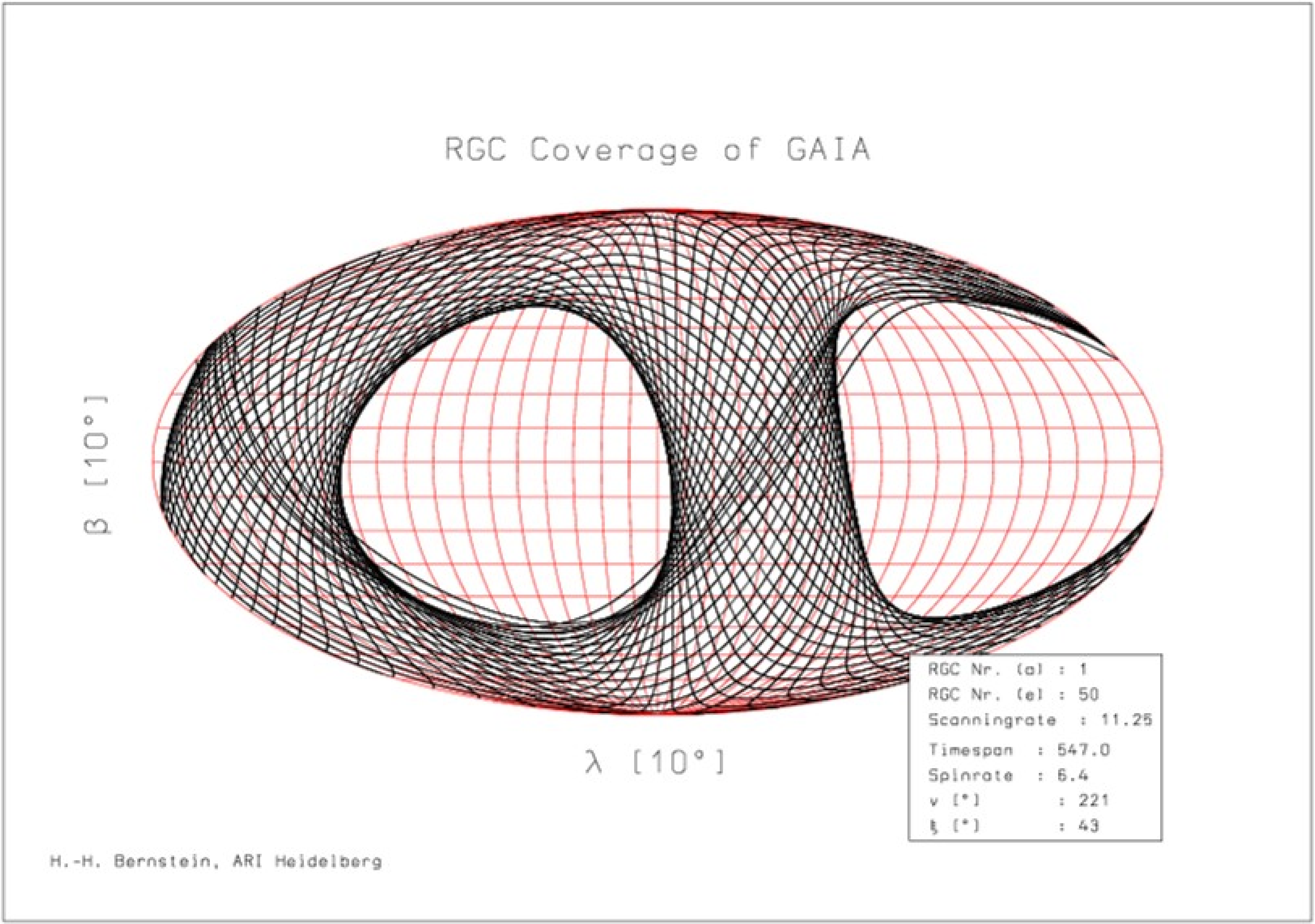


Figure courtesy
Karen O'Flaherty

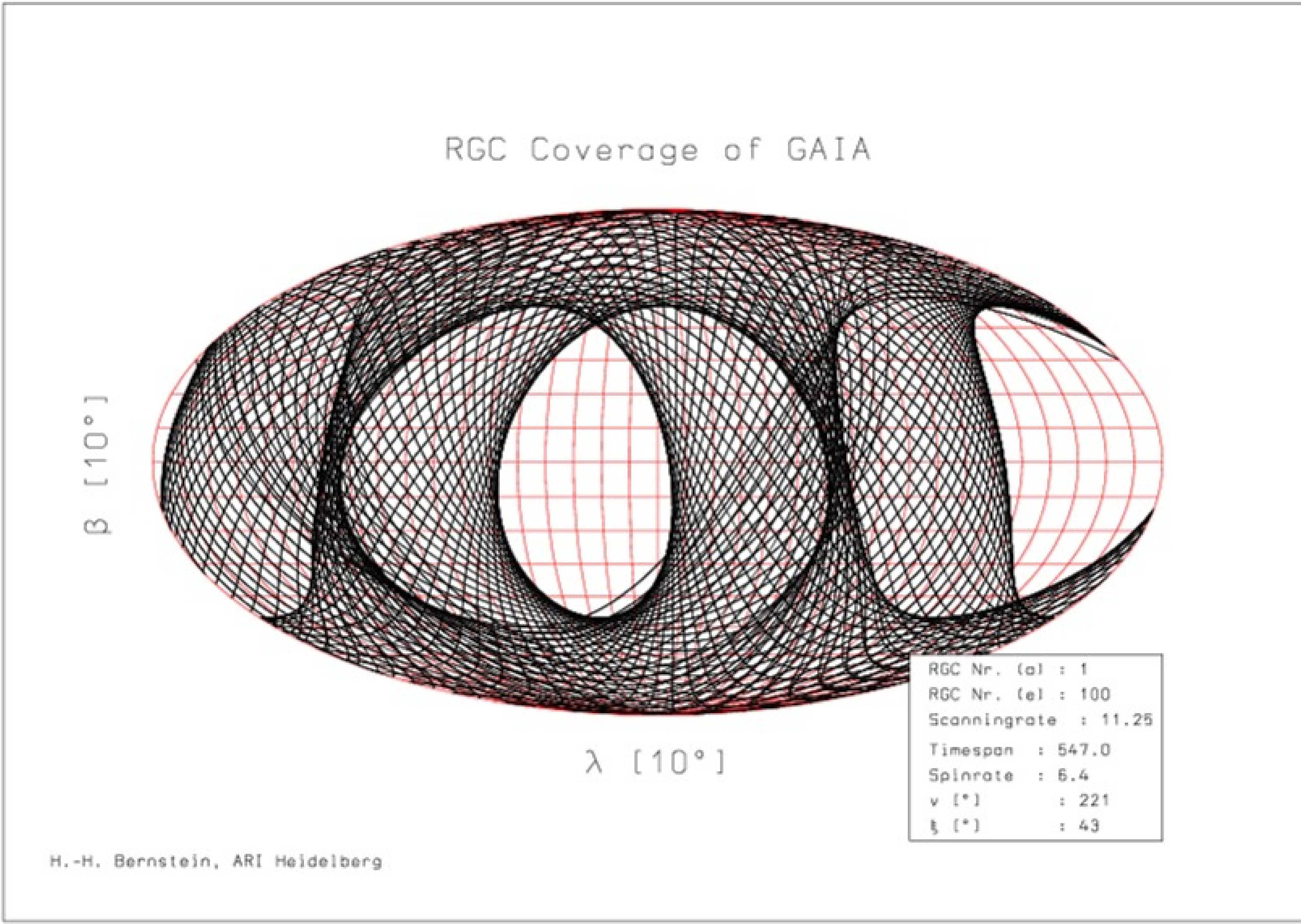
Spin axis	45° to Sun
Scan rate:	60 arcsec/s
Spin period:	6 hours

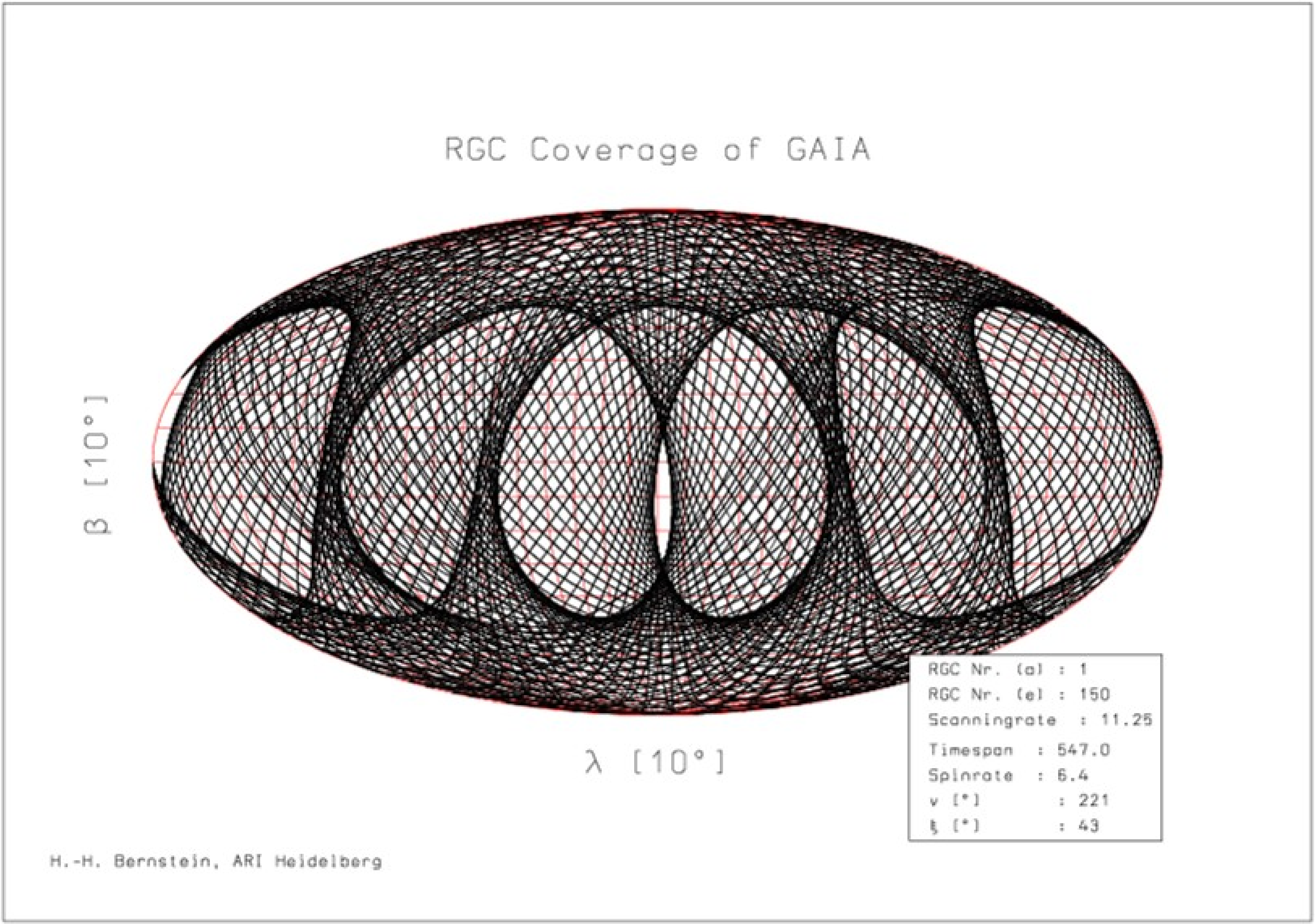


RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 2
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 50
H.-H. Bernstein, ARI Heidelberg



RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 50
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
H.-H. Bernstein, ARI Heidelberg


RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 100
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
H.-H. Bernstein, ARI Heidelberg


RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 150
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
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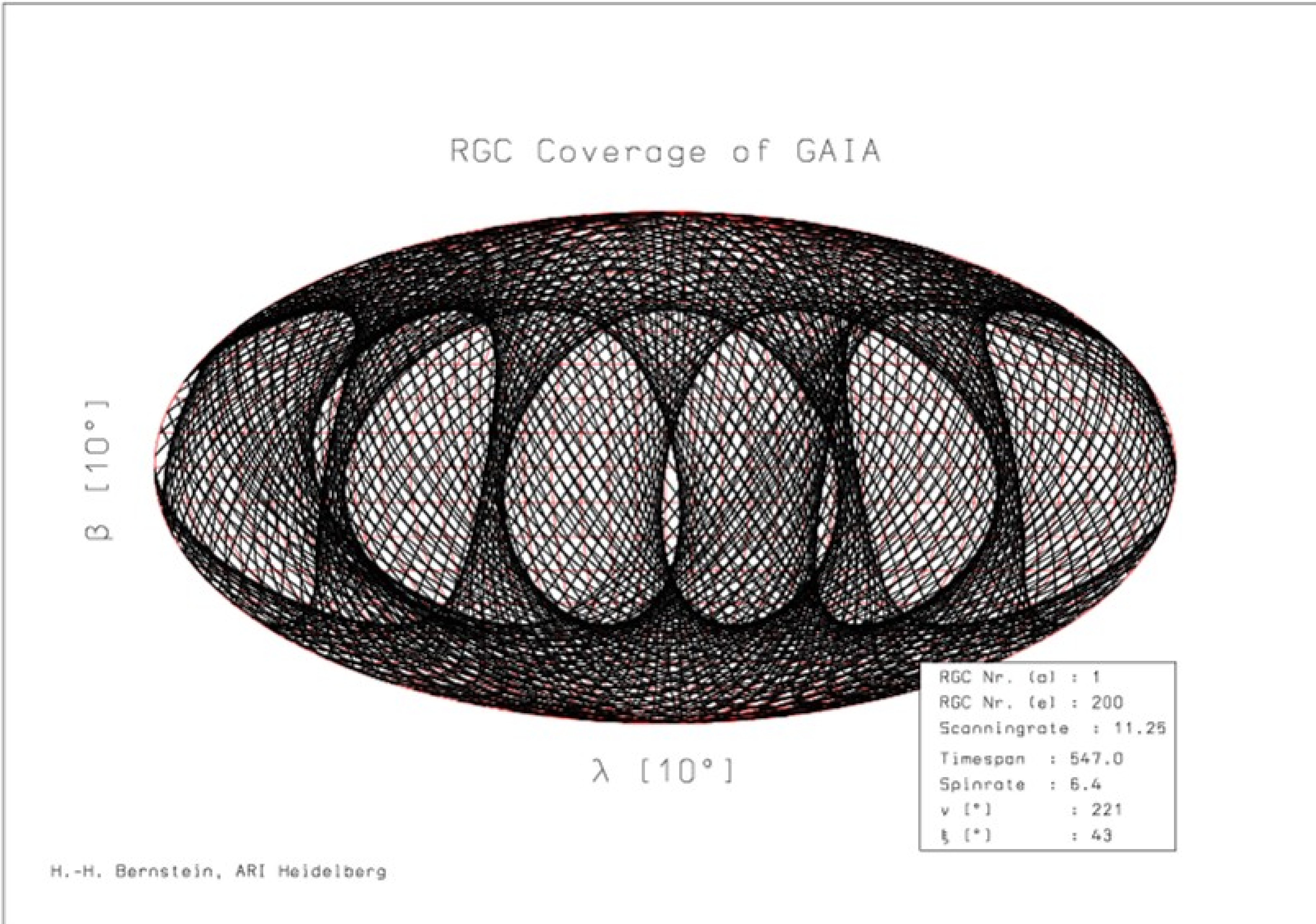
RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 200
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
H.-H. Bernstein, ARI Heidelberg

Gaia – the first weeks

- 19th December, 2013, 09:12 UTC, Gaia lifts off to start a new era in Galactic astronomy!

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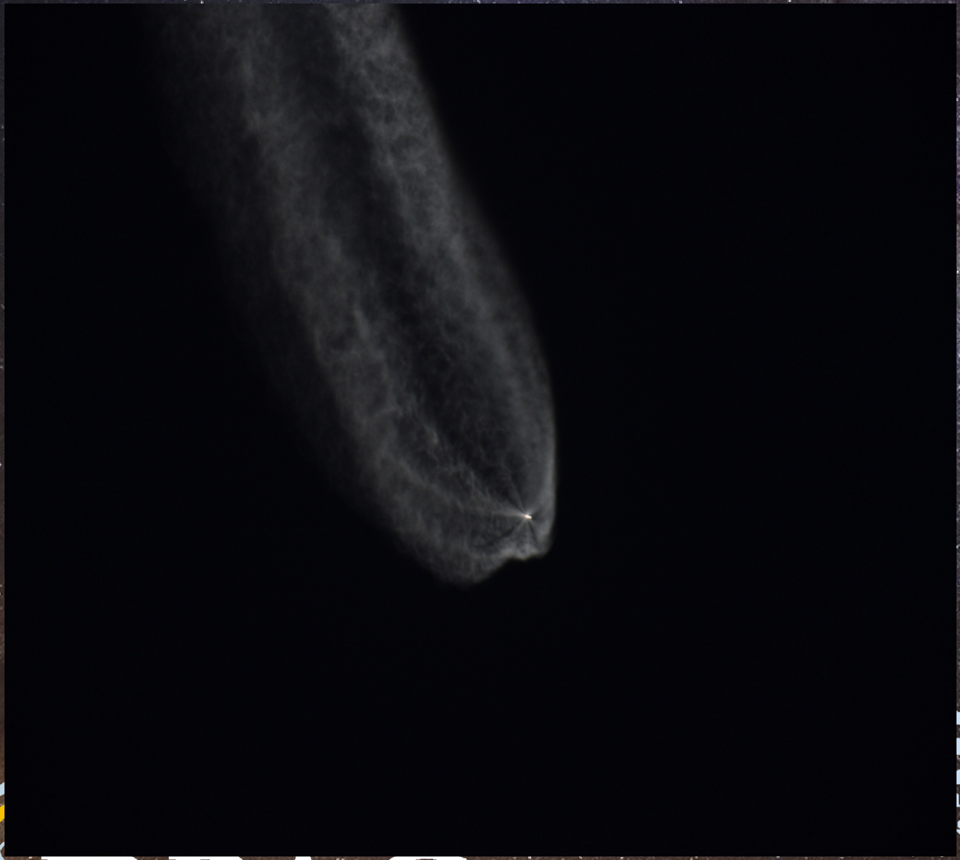

Gaia – the first weeks

- Day 1 after ~1 hr, Sunshield opens
- Day 2 slew to a solar aspect angle of 45º
- Rotation switched on
- Heating to remove any contamination begins
- Jan 7 – 14 L2 insertion
- Jan 3 first light on CCD
- One by one, all systems are turned on and tested

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Gaia – the first weeks

- Many systems work well, some even exceed expectations
  - CCD's, source extraction, microthrust boosters
- As in all such missions, there are also some problems
  - Stray light issue is currently being analysed
  - Some problems reported on in mass media (e.g. spiegel-online) are non-issues

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Gaia – the first weeks

·Commissioning phase

- ·Ecliptic Poles Scanlaw (EPSL) covering both Ecl. Poles (for which deep catalogues exist)
- ·Test of all detectors, algorithms, etc.
- ·Finetuning of source detection, limiting magnitudes, spin rate
- ·Normal operations started July 25
- ·nominal scanniong law since August 22
- ·Last week: additional heating cycle the remove contamination

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Gaia status

- All systems on board are working fine
  - All 102 CCDs and PEM units nominal sensitivity, readnoise, dark currents
  - Clean telescopes have nominal throughput
  - Target image quality and tiny focal-length difference achieved
  - ACS working extremely well (s/w and all hardware)
  - Power system, atomic clock, phased-array antenna, mass memory, …
  - Internal metrology interferometer very precise (but ….)

  - Sole functional defect: intermittent malfunction of one MPS thruster
    -> redundant system in use

- But there are also some nasty problems
  - Extended commissioning phase needed
  - Much more complicated calibration task
  - Some performance restrictions

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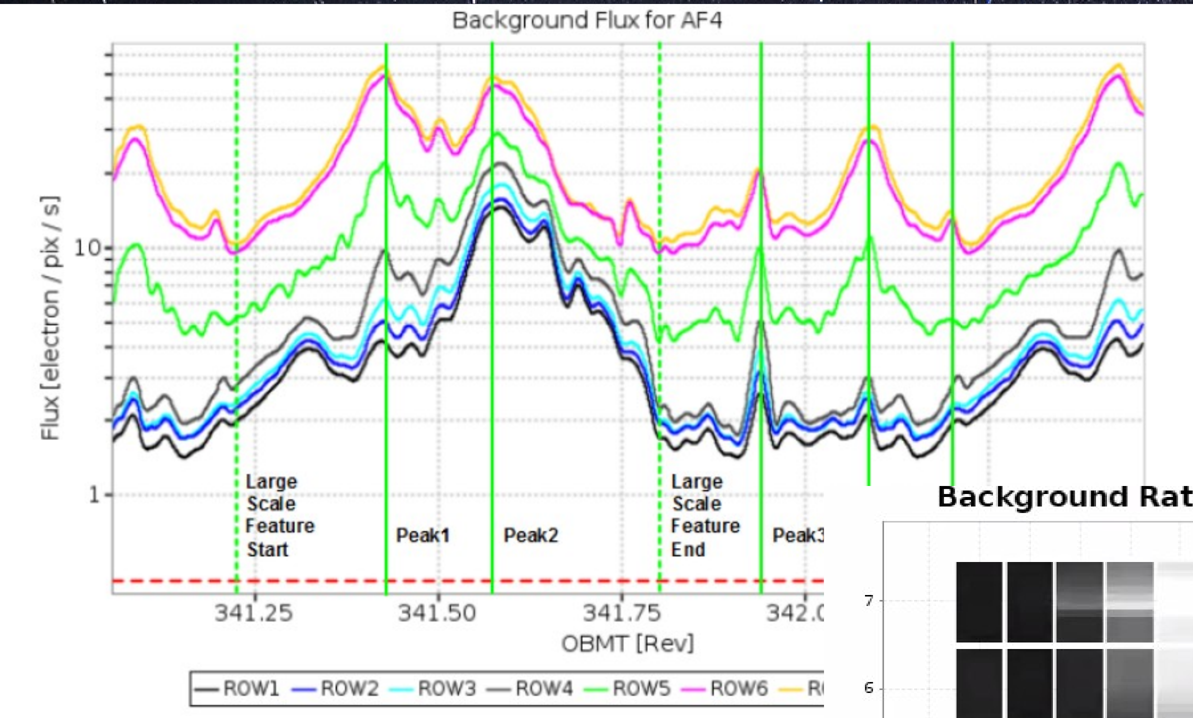
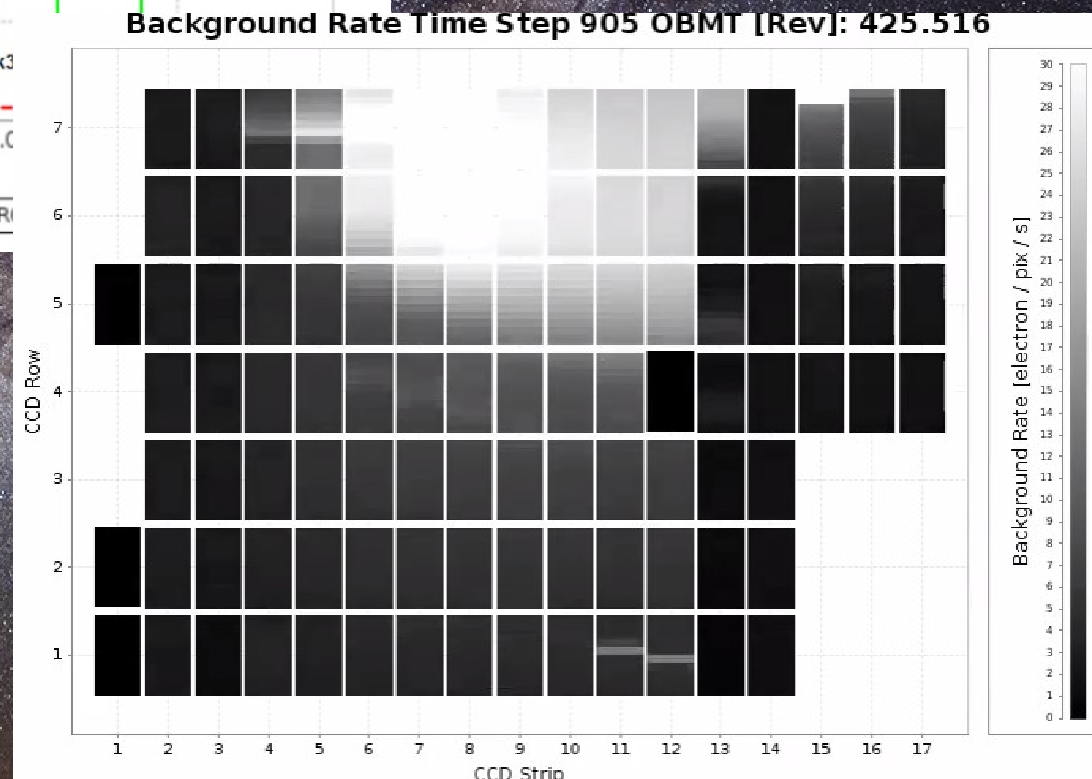
Excessive Straylight



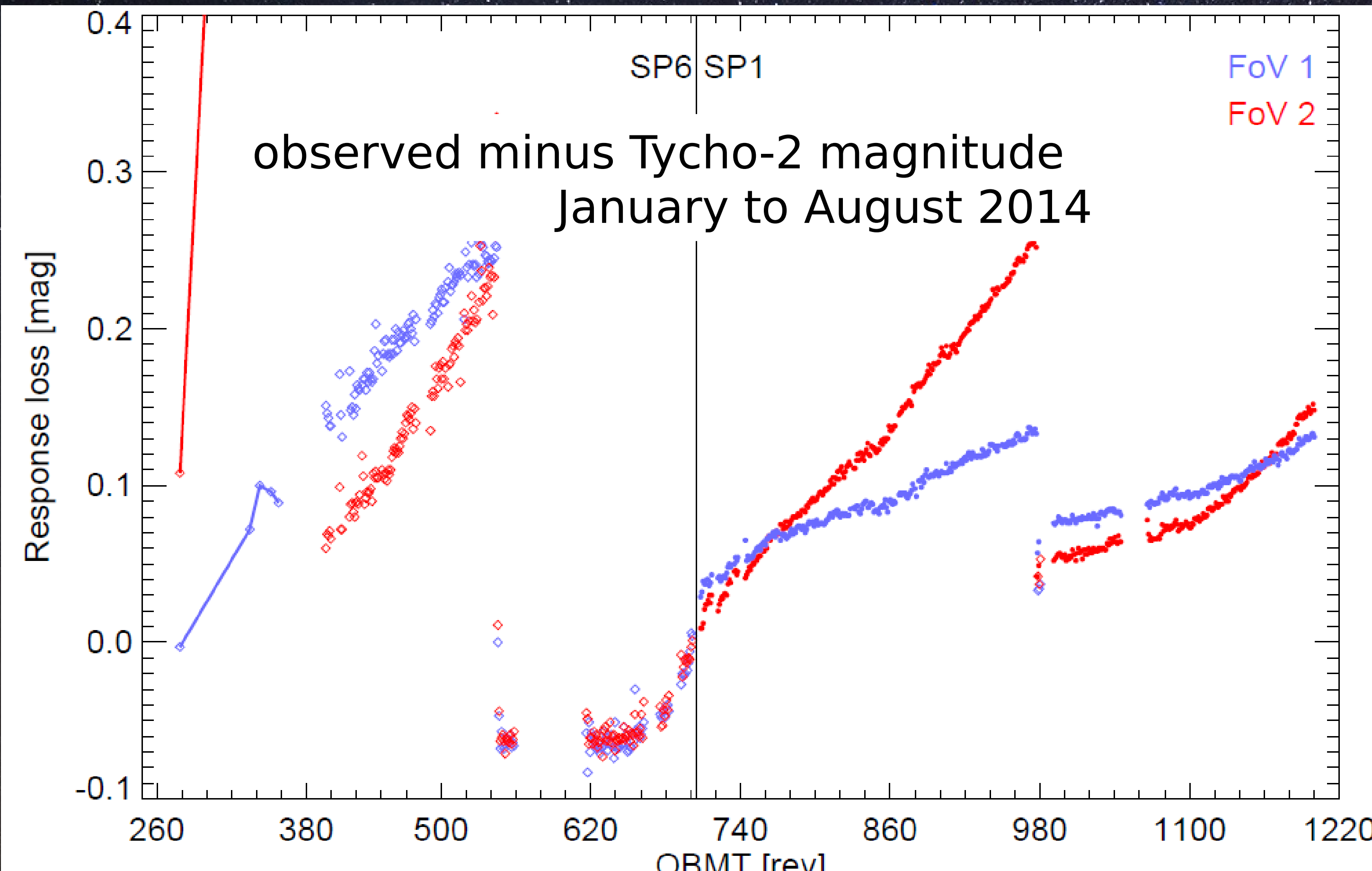


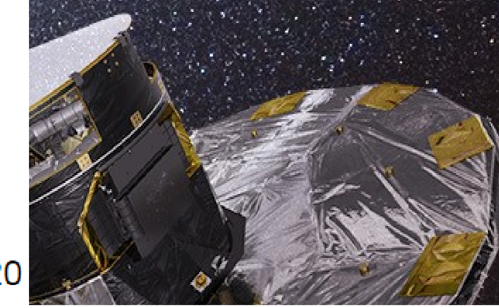
- **Diffracted sunlight**
- **Milky Way**
- **Bright point objects**

1. **Sunshield**
2. **Insufficient baffling**

Courtesy: U. Bastian

Contamination of the optics

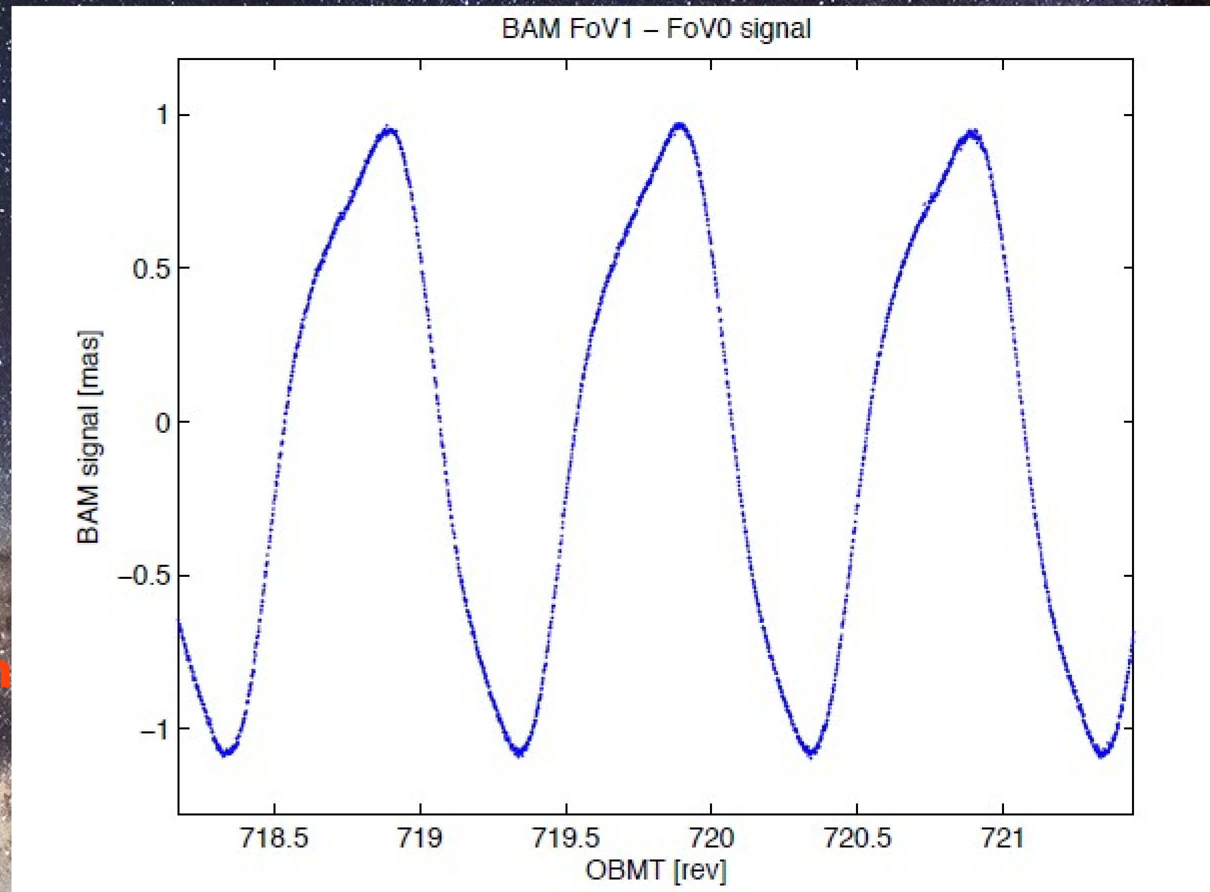




- **Three decontaminations done**
- **Interruptions of observations**
- **Disturbance of thermal state**
- **Contamination rate is decreasing**
- **Future evolution is unpredictable**

Courtesy: U. Bastian

Basic-angle oscillations



tied to the sun

very stable

1 mas = 5 10E-9 rad < 4 nm movement of the main-mirror edges ~ 10 Si atoms

(and even much less if it is a different mirror)

Noise: a dozen or so picometers !

Courtesy: U. Bastian

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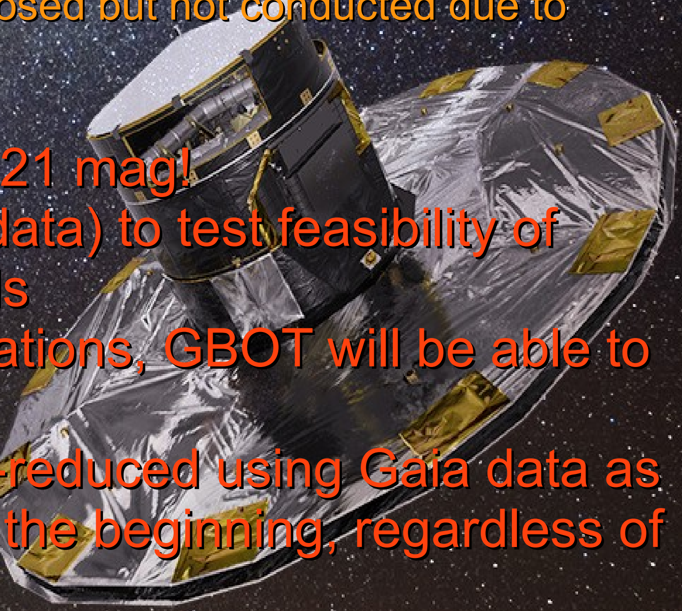
- GBOT (Ground based optical tracking) serves to allow the full exploitation of Gaia's potential even for the best measured stars (aberration) and for solar system parallaxes
- Specifications of knowledge of state vector (6D vector connecting Gaia & Earth, resp Gaia & Solar system barycentre) 150 m & 2.5 mm/sec
- Astrometric reduction system and small network of 1-2 m telescopes was set up, assuming a brightness of Gaia of 18 mag.
  - Assumptions were based on experience with other L2-spacecraft (WMAP, PLANCK) and theoretical considerations. Empirical studies were proposed but not conducted due to costs
- GBOT system was fully operational at launch
- After launch it became clear, that Gaia will be 21 mag!
- 1 year reassessment phase (while collecting data) to test feasibility of GBOT, including the theoretical limits of signals
- With larger telescopes (2 ,m+) and some limitations, GBOT will be able to deliver most of the required precision
- Accuracy: will only be known, when data is re-reduced using Gaia data as reference material (this is an uncertainty from the beginning, regardless of Gaia's magnitude)



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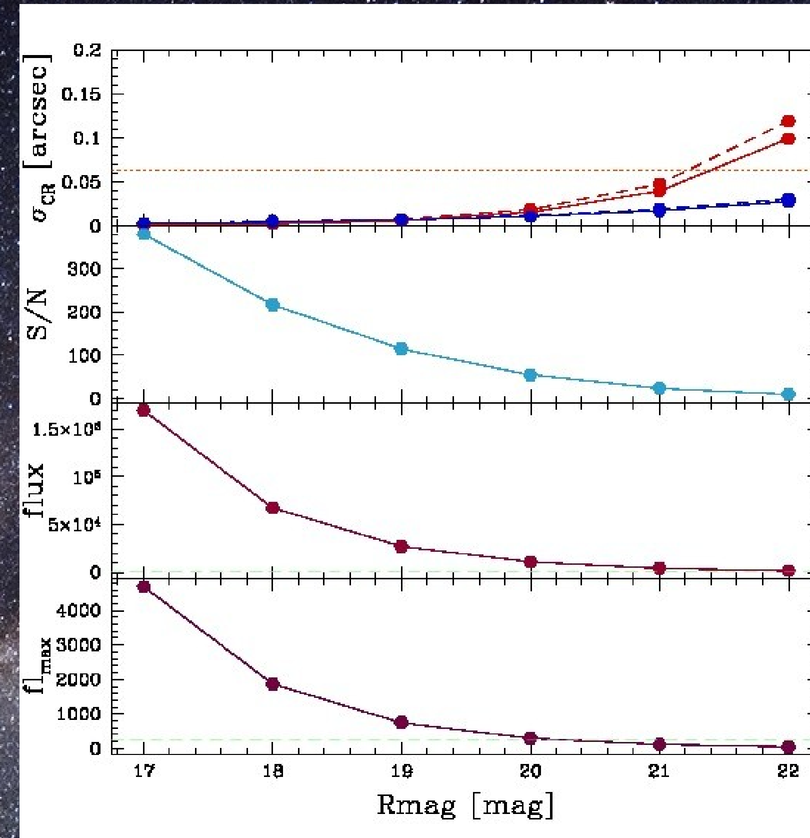
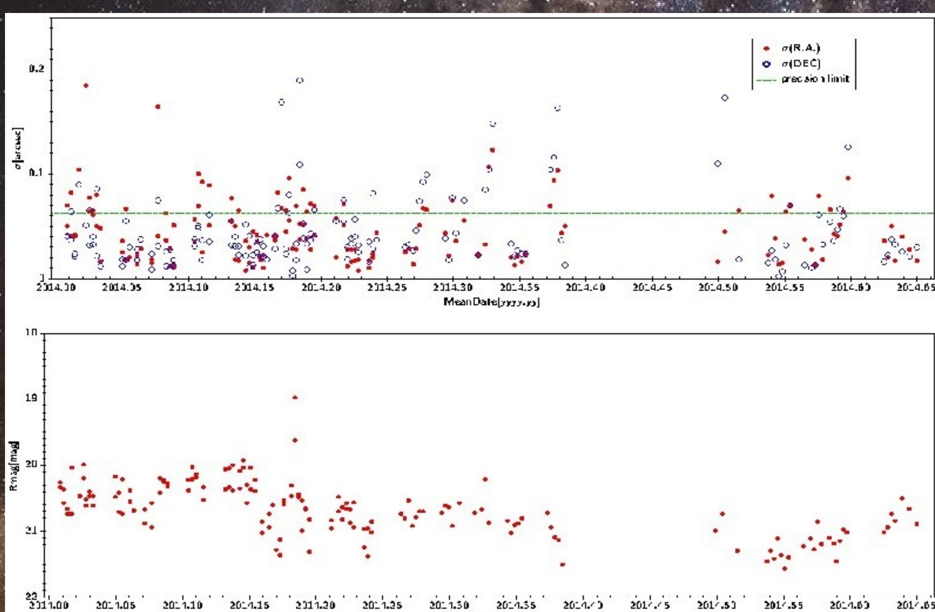
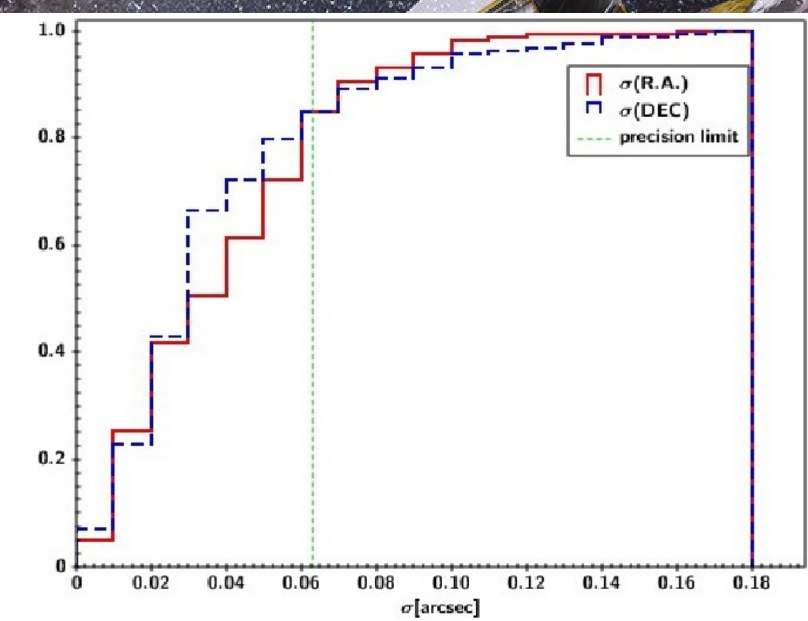
Theory: Cramer Rao limits for VST



Data: VST can deliver data within specs for 80% of the time

(left: top mean offsets and scatter in respect to calculated orbits, bottom r- brightness Right: precision histogram)





And an “external” problem

- Many more micro-meteorite hits than expected from LEO and GEO
- Attitude disturbance; attitude reconstruction impaired
- It is not severe, is more a nuisance than a problem
- We can of course not do anything about it

- **This may in fact be the very first scientific discovery of Gaia !**

Early astrometric precision assessment

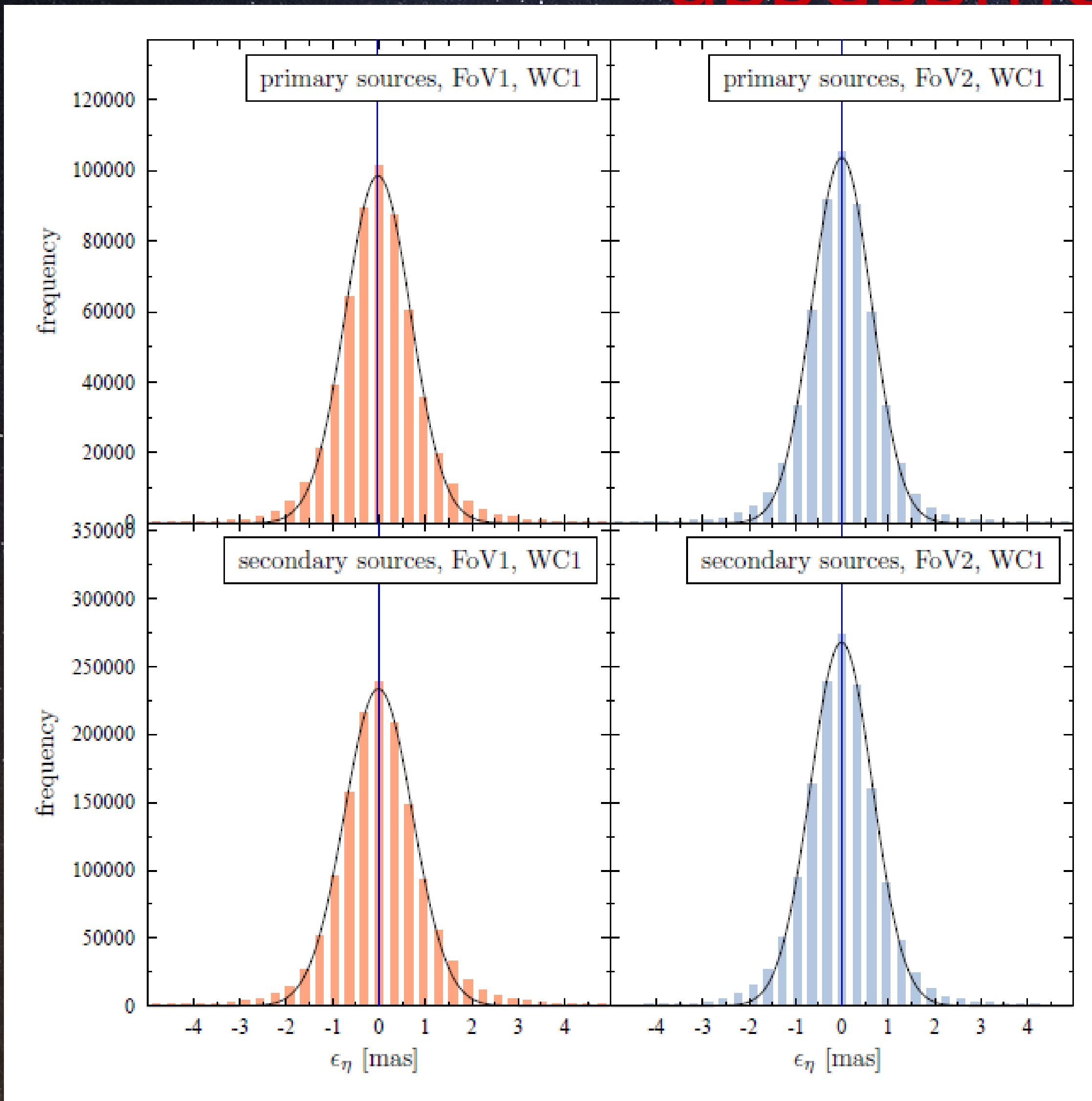
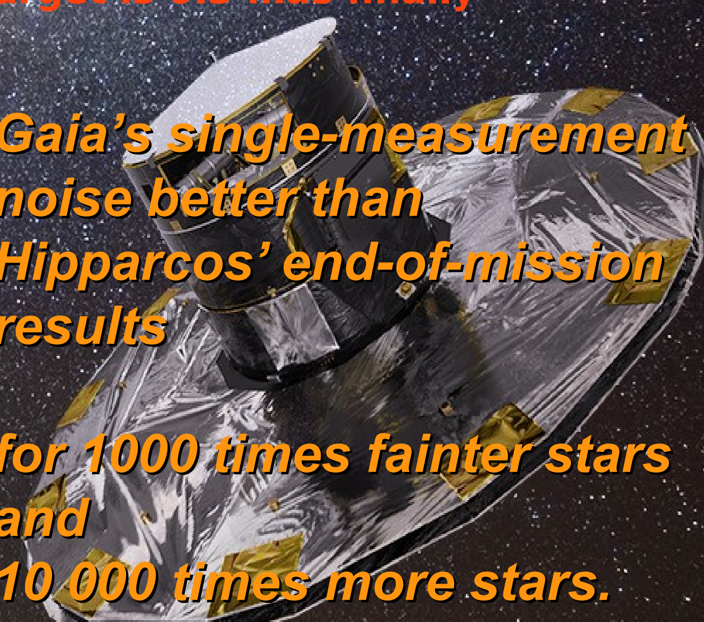


Figure courtesy First Look team

ODAS residuals:

0.6 mas at G=15 in June/July

- **Coarse attitude model**
- **Poor PSF calibration**
- **No source colours**
- **Imperfect straylight correction**
-
- **It was 2 mas in April/May**
- **Target is 0.3 mas finally**



Gaia's single-measurement noise better than Hipparcos' end-of-mission results

for 1000 times fainter stars and 10 000 times more stars.

Very roughly reduced yet ...

Courtesy: U. Bastian

Gaia - performance

Expected end-of-mission parallax standard errors

for solar-type stars:

V= 3...12   14 micro-arcsec

V= 15   24

V= 20   540

V= 21   ~900   new, being tried

End-of-mission photometric broad-band std errors [mmag]:

	B1V			G2V			M6V		
G [mag]	G	BP	RP	G	BP	RP	G	BP	RP
15	1	4	4	1	4	4	1	7	4
18	2	8	19	2	13	11	2	89	6
20	6	51	110	6	80	59	6	490	24

End-of-mission radial-velocity standard errors

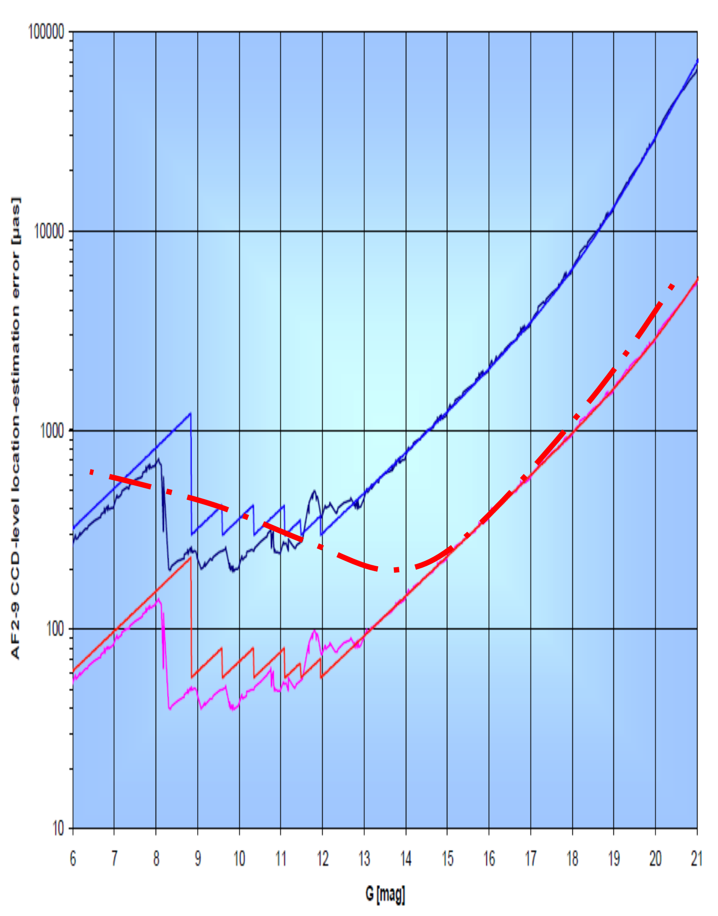
for solar-type stars:

G< 12.3   1 km/s

G= 15.5   15 km/s

G= 16.5   ---

Single-measurement precision;
red= along, blue = across scan



Courtesy: U. Bastian

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Gaia – data releases

- Launch+22 months release, currently foreseen mid 2016
  - α,δ, G-mag, if 90%of sky covered
  - Single stars
- Launch+28 months release, early 2017
  - 5 par astrometrics for single stars
  - BP/RP integrated photometry
  - RVs for single stars
- Launch+40 months release
  - Full astrometry for binaries with 2months$<T_{orb}$75% observing time
  - Object classification, astrophysical parameters incl. RP/BP/RVS spectra for wellbehaved objects

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Gaia – data releases

- Launch+65 months release
  - Variable star classification, epoch photometry
  - Solar system results, preliminary orbital solutions
  - Non-single stars catalogues
- ***Final release (2020/21)***
  - **Everything!!!!!**

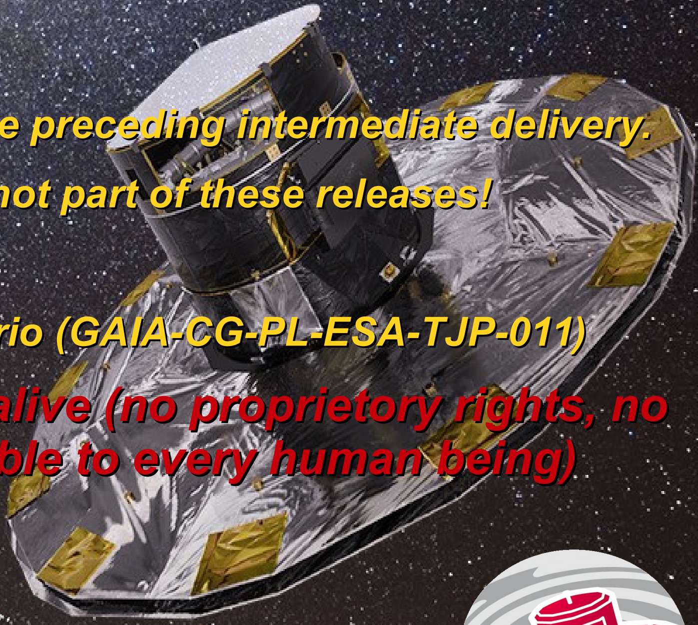
All steps include the a redelivery of the data delivered in the preceding intermediate delivery.

Science alerts will be issued as soon as possible, and are not part of these releases!

Exact release dates subject to shifts within schedule

Reference: T.Prusti: Gaia Intermediate Data Release Scenario (GAIA-CG-PL-ESA-TJP-011)

Condition of accessing data at time of release: be alive (no proprietory rights, no protected data times, release is immediately available to every human being)



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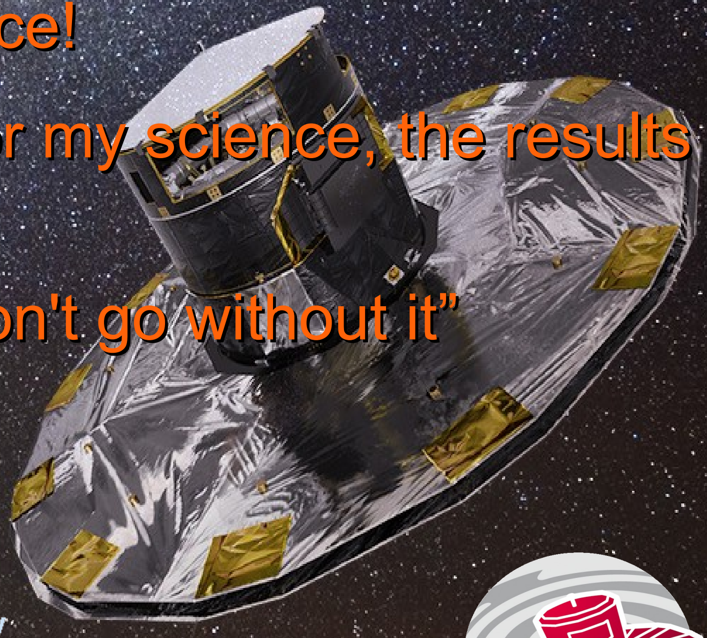
End: Part 1

- Stay tuned to see what bright and exciting new science one can do with Gaia brought to you bzy the 2nd part, the talk by Francesca Figueras
- Gaia, there is nothing like this, Gaia,....,Gaia, Gaia, Gaia will change the way you do or look at science!
- "ever since I started using Gaia data for my science, the results have been overwhelming"
- "Gaia, I was sceptical at first - now I won't go without it"

Quotes from satisfied customers



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