The overture to a new era in Galactic science: Gaia's first data release

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Bogota, 28th September 2016

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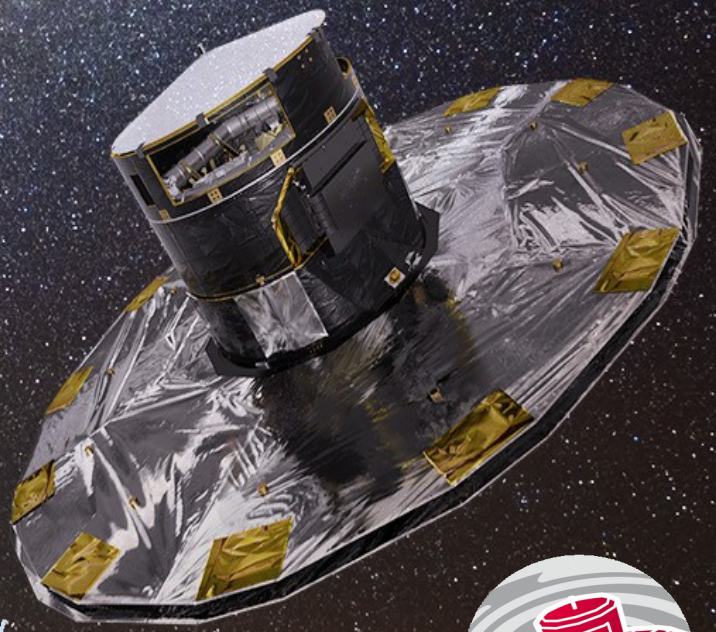
Gaia facts

- The promise
- The optical plane
- Scan law
- Status
- Timeline of data releases



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Gaia – the promise

- 1+ billion stars to 20.7th magnitude, 1% of MW stars
- Full 5 parameter astrometric data for 10^9 stars
  - Between 10 and ~700 μas precision for parallaxes, positions and proper motions!
- Multi colour (spectro)photometry of 10^9 stars
- High resol. spectroscopy for 10^8 stars to 16th mag
  - Radial velocities, abundances, rotation velocities for the brighter objects.

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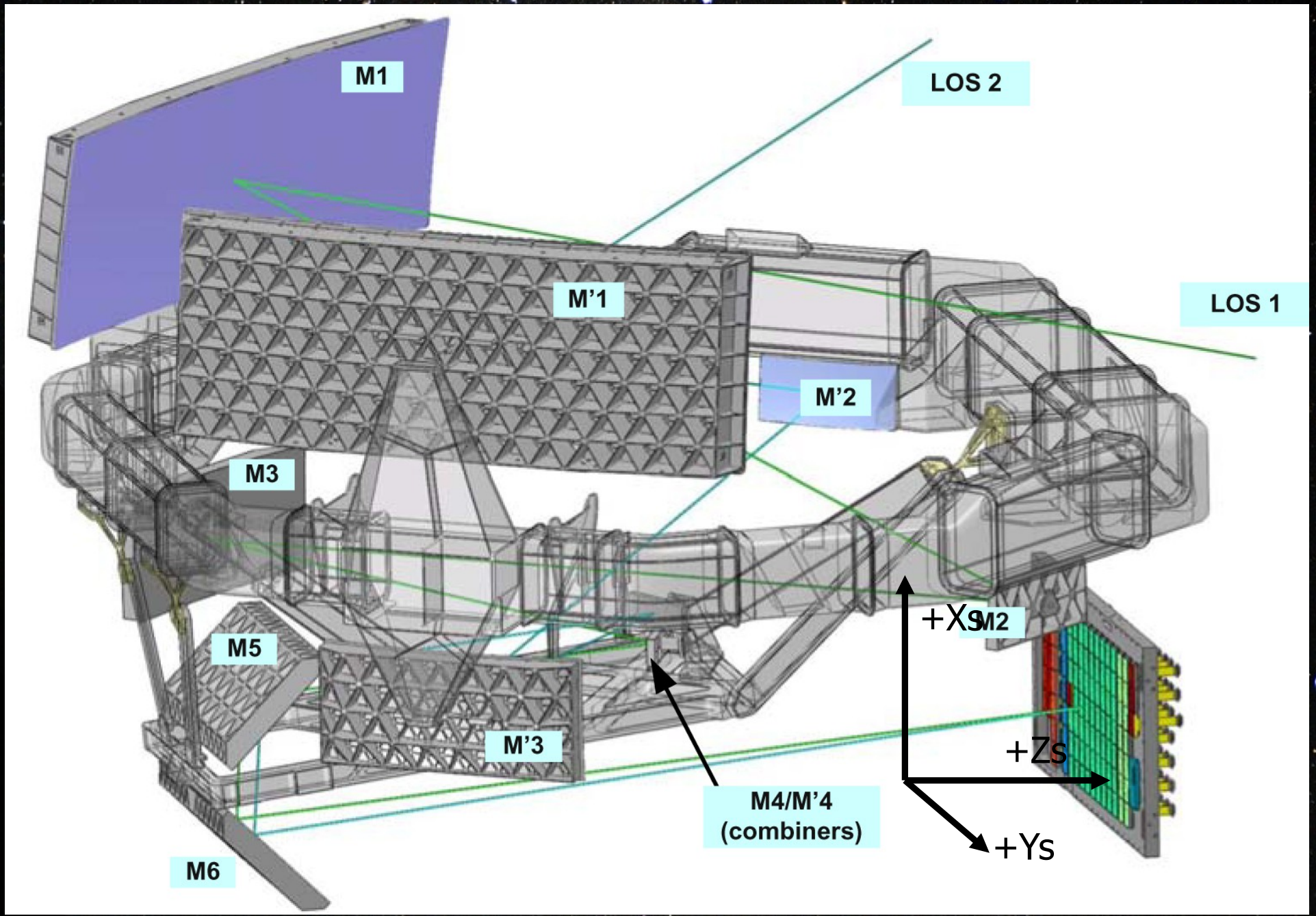
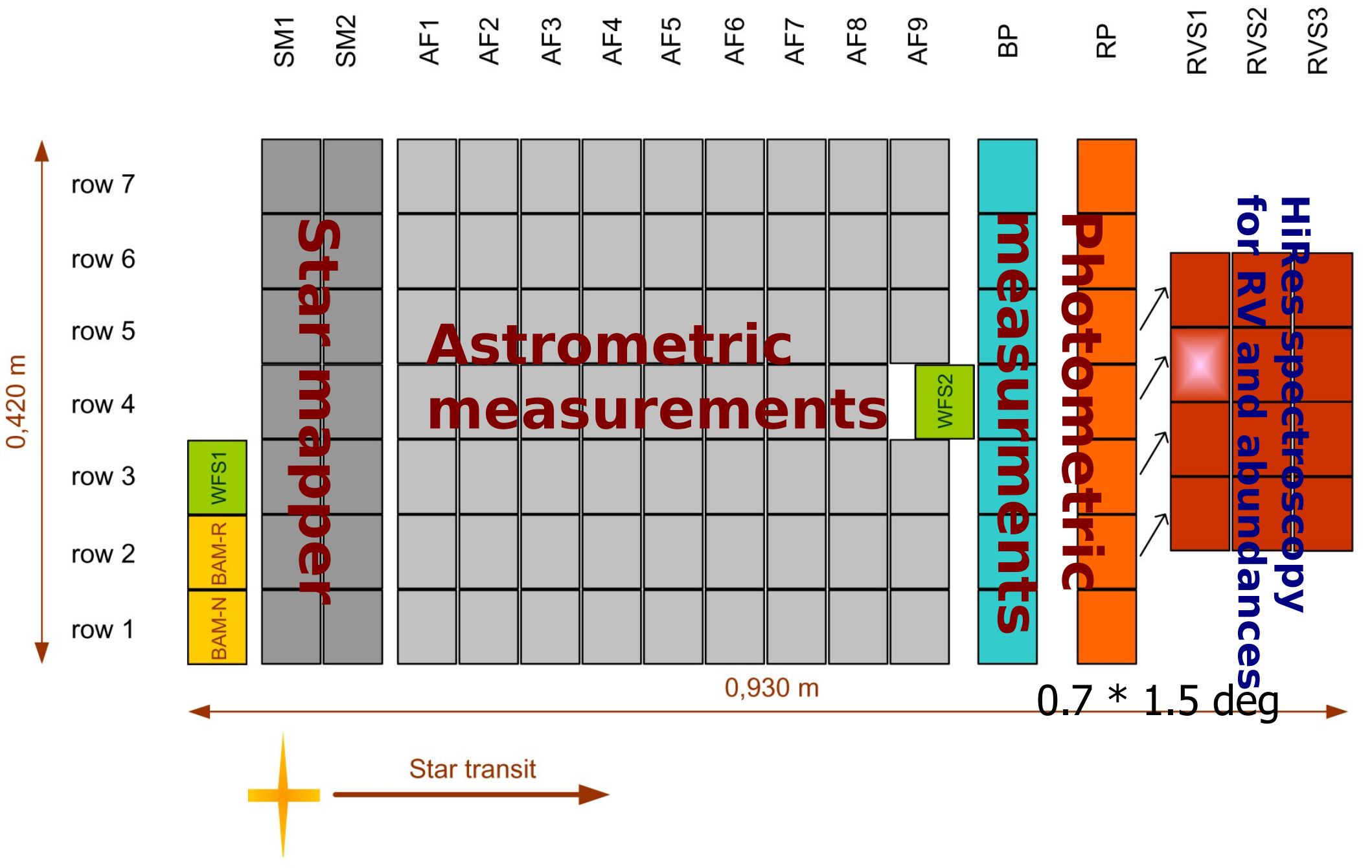
Gaia: the optical assembly

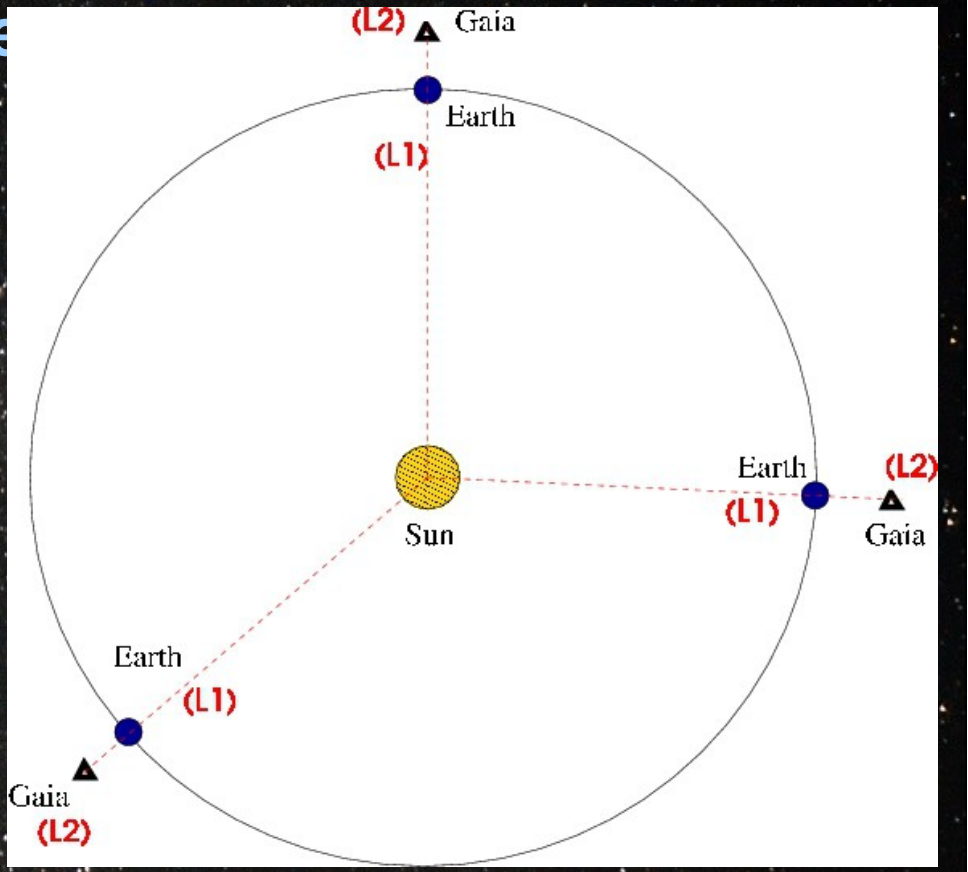


Gaia: the focal plane



Gaia's Position near Earth-Sun Lagrange Point L2

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

Sky Scanning Principle

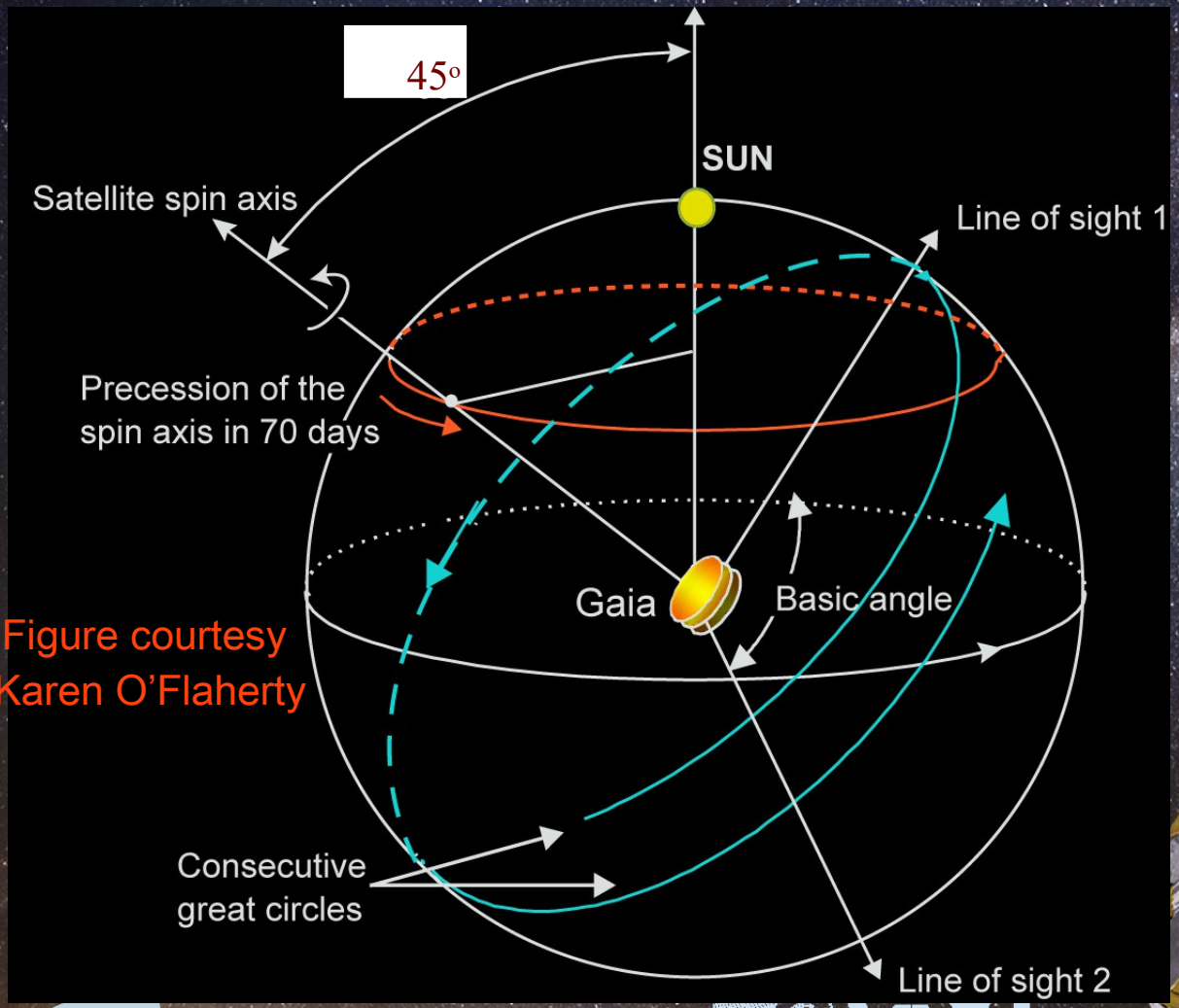


Figure courtesy
Karen O'Flaherty

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

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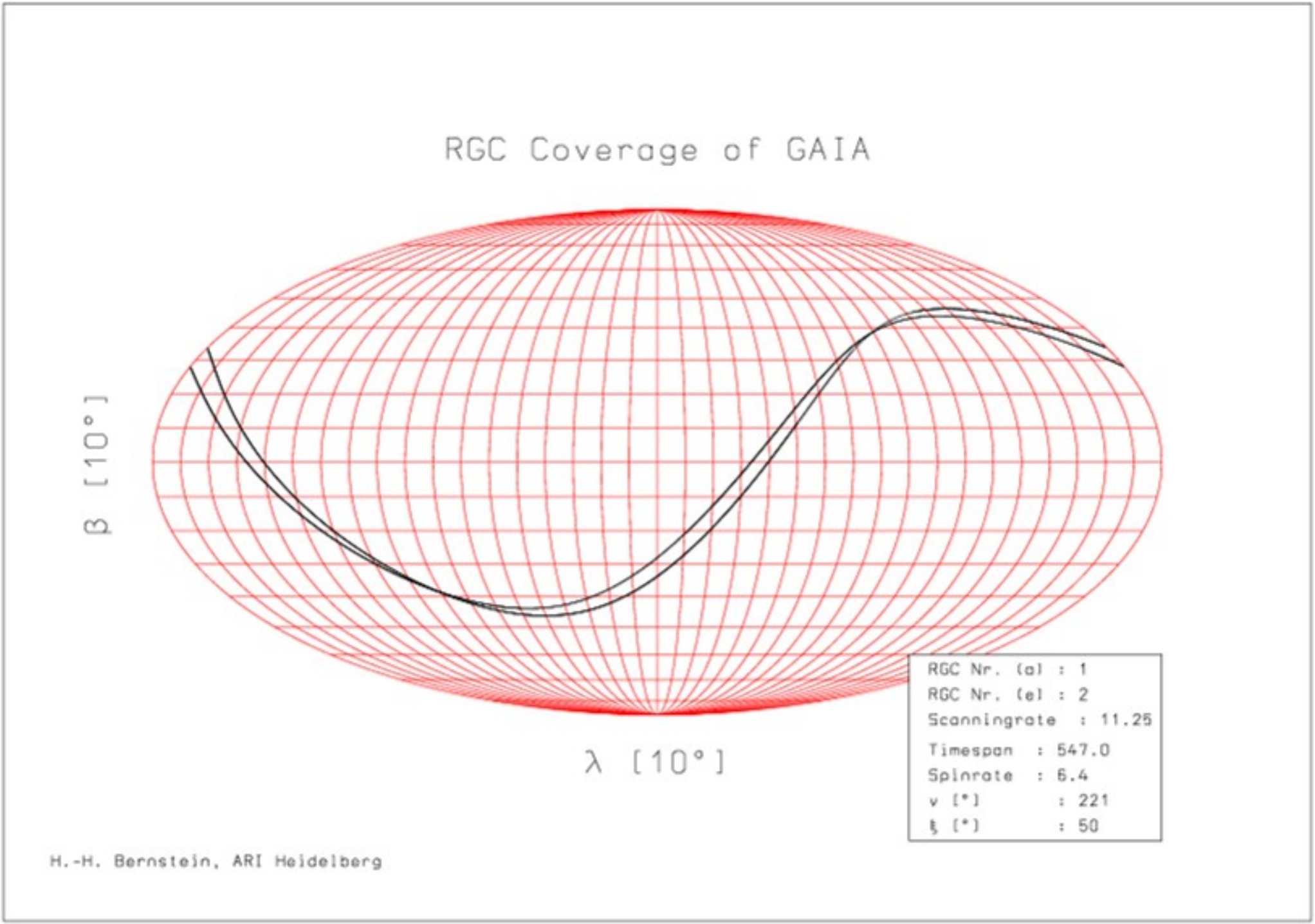
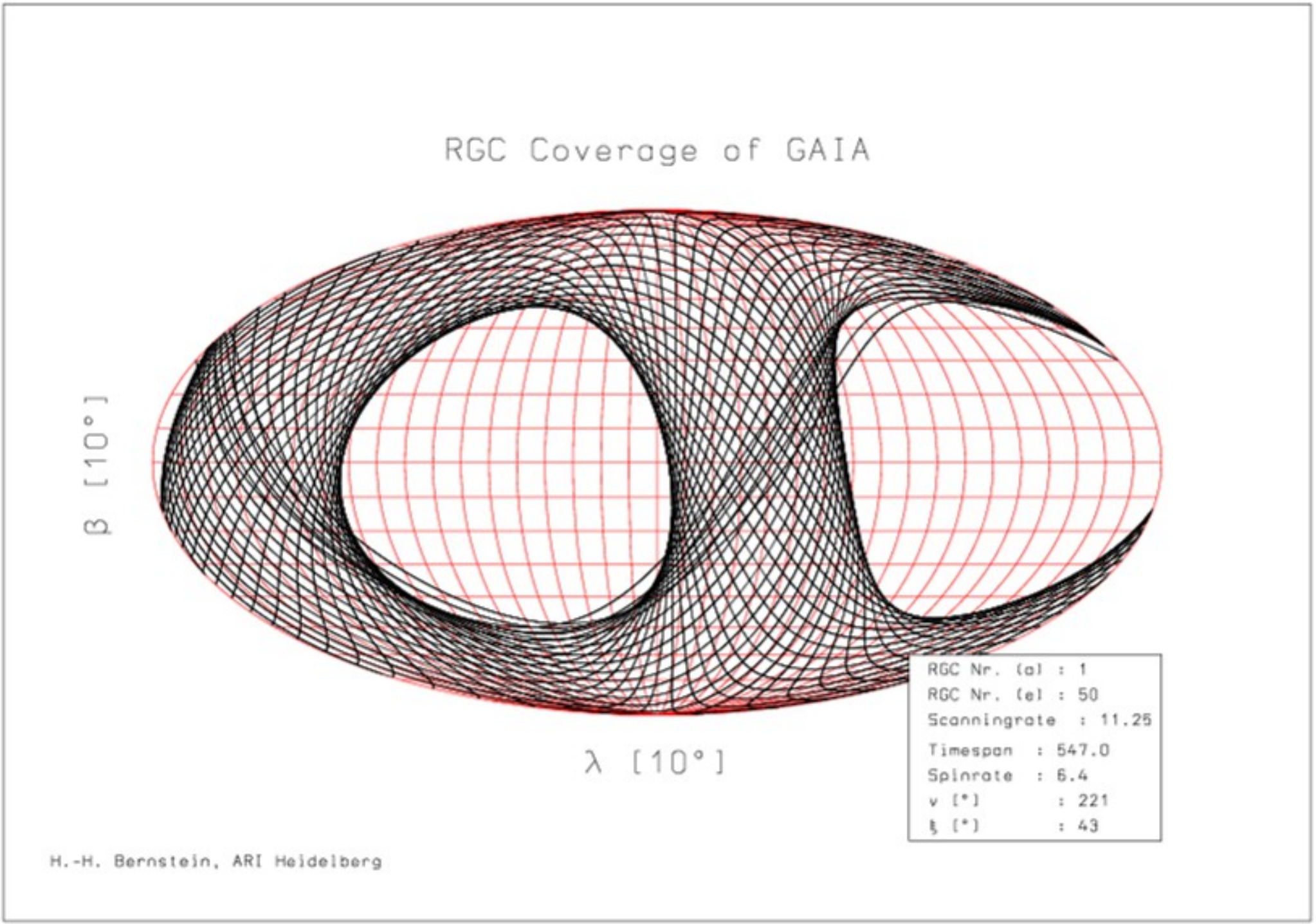

RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 2
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 50
H.-H. Bernstein, ARI Heidelberg


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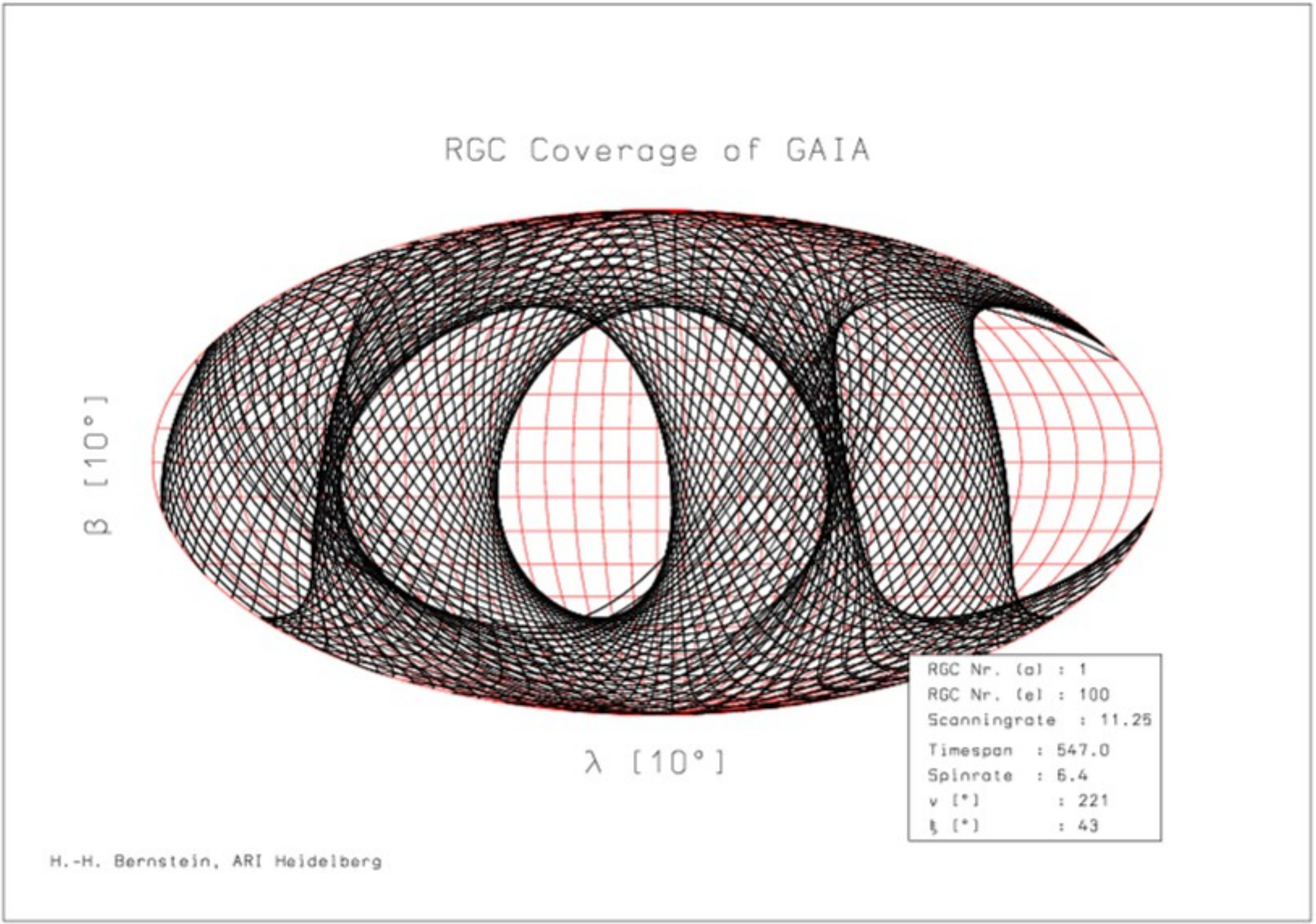
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
H.-H. Bernstein, ARI Heidelberg


RGC Coverage of GAIA
β [10°]
λ [10°]
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RGC Nr. (e) : 100
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Timespan : 547.0
Spinrate : 6.4
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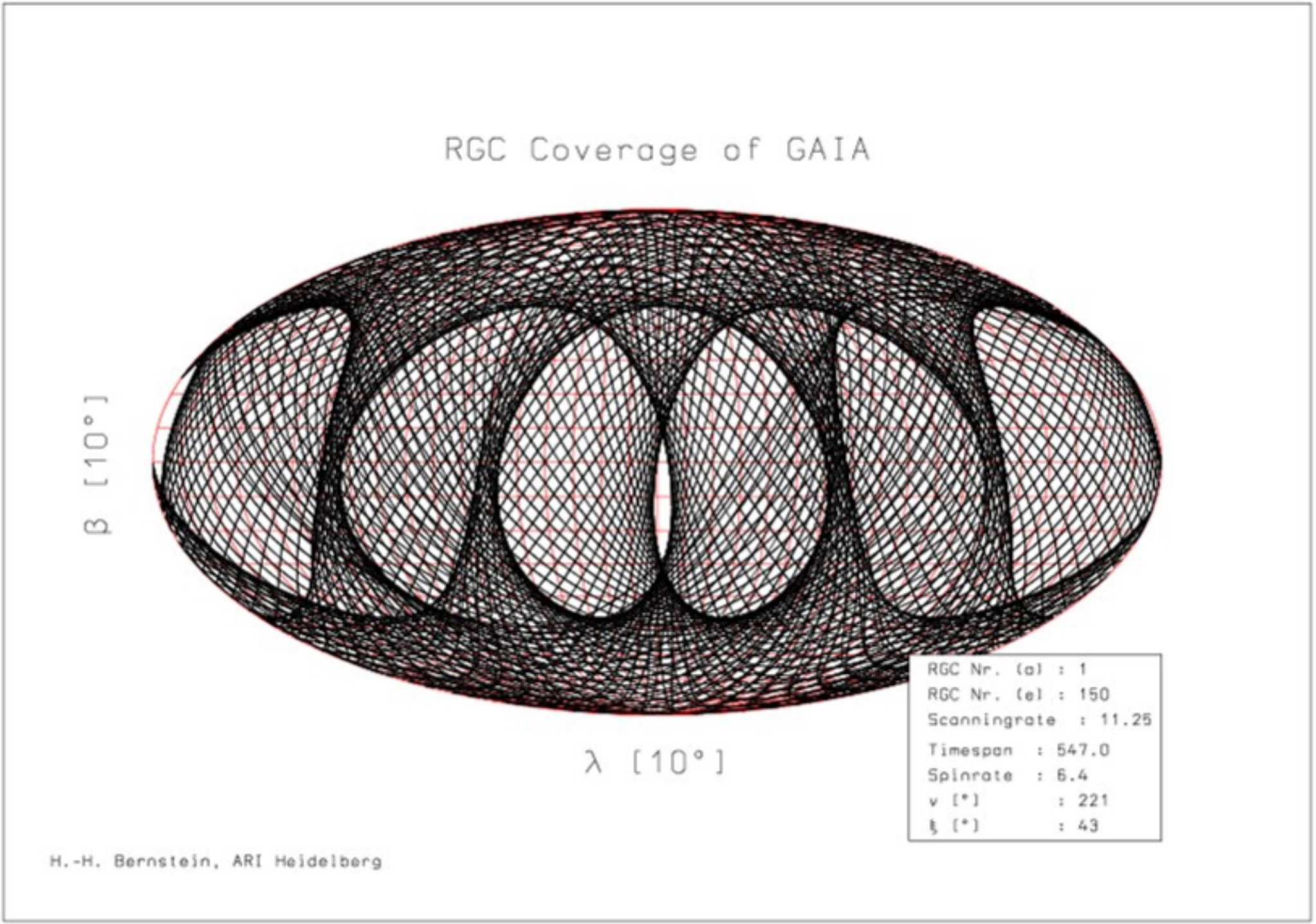
ξ [°] : 43
H.-H. Bernstein, ARI Heidelberg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λ [10°]
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RGC Nr. (e) : 150
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Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
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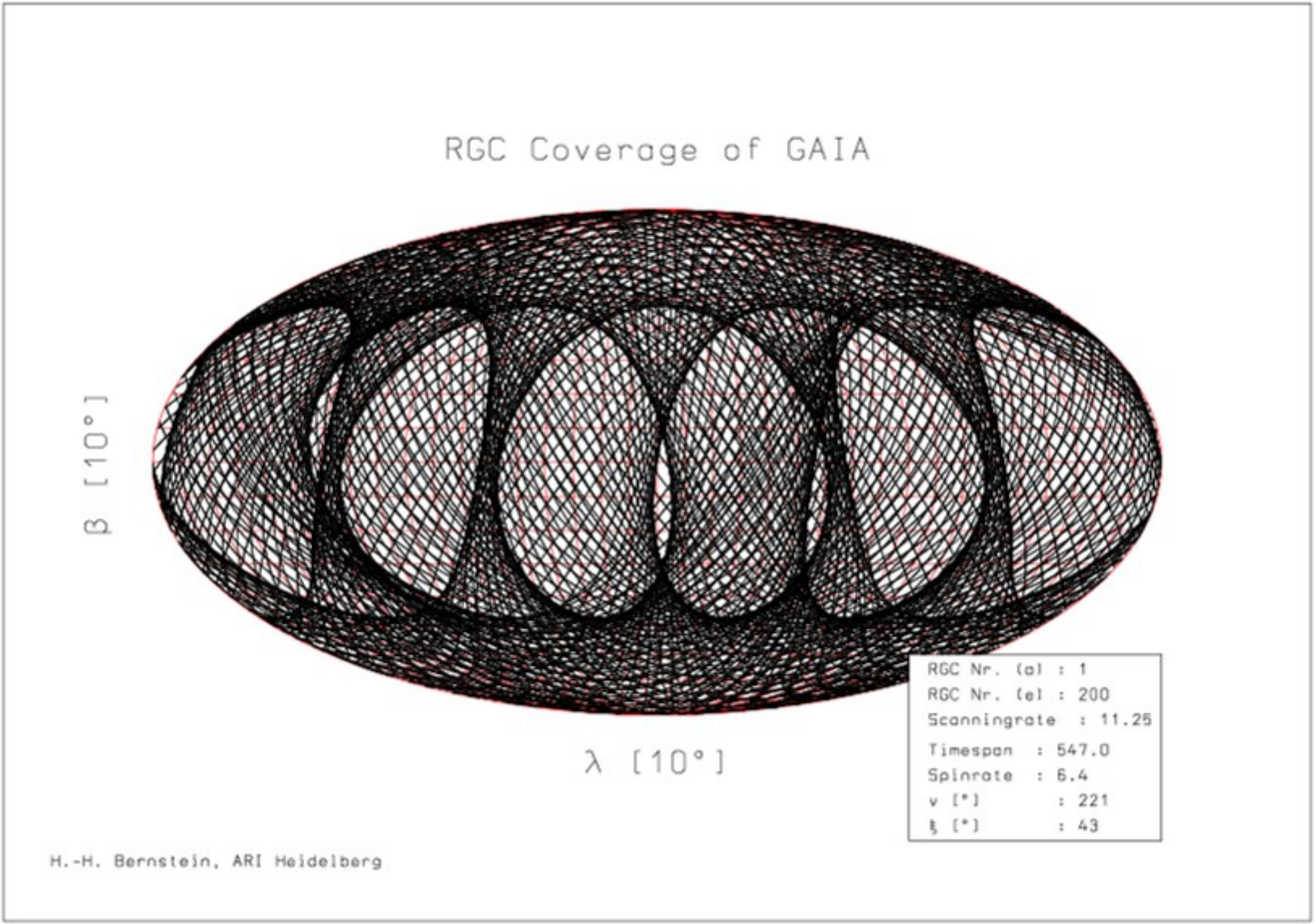
RGC Coverage of GAIA
β [10°]
λ [10°]
RGC Nr. (a) : 1
RGC Nr. (e) : 200
Scanningrate : 11.25
Timespan : 547.0
Spinrate : 6.4
ν [°] : 221
ξ [°] : 43
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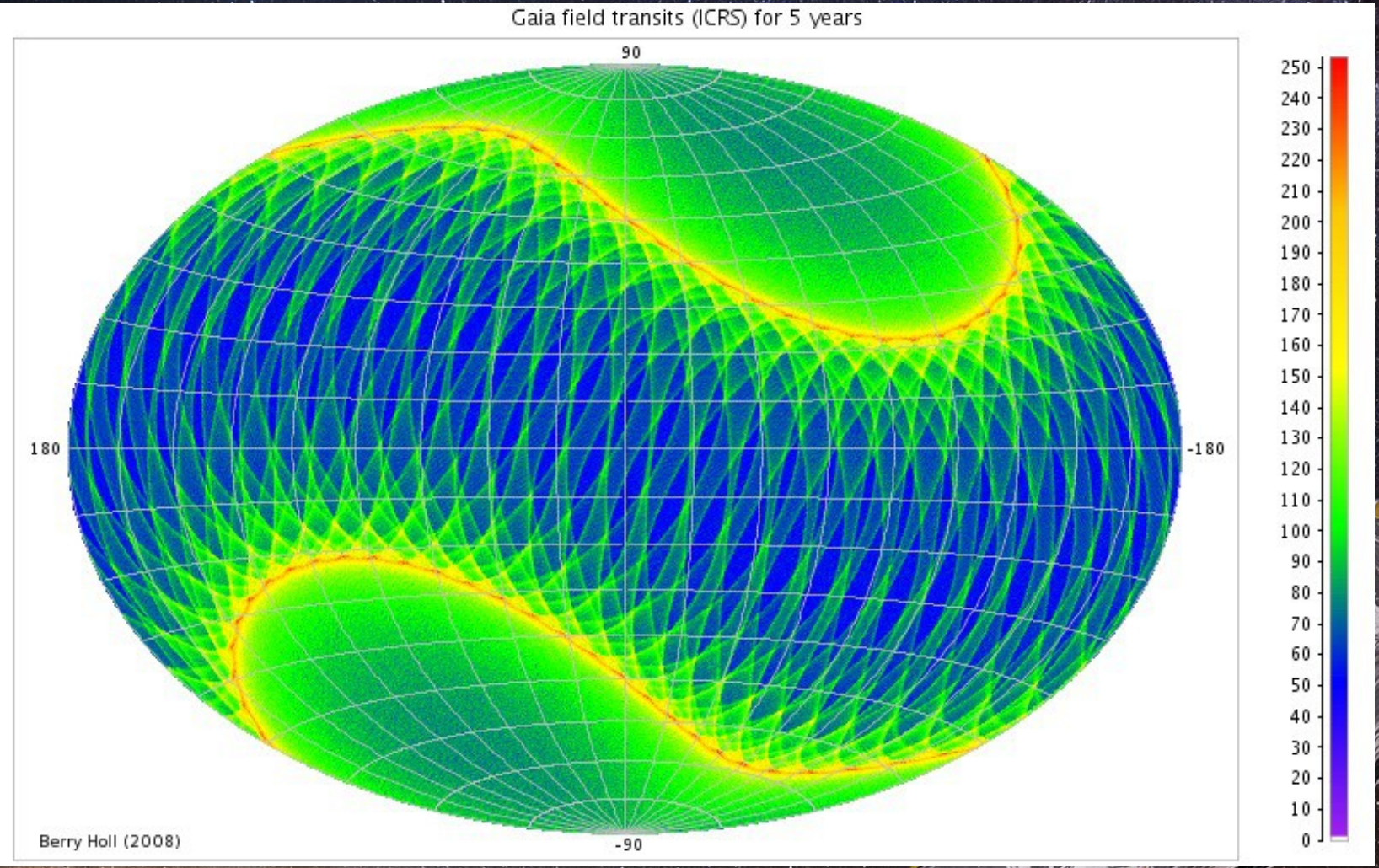
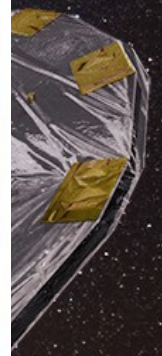
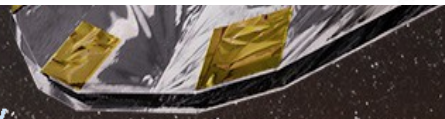
Gaia – end of mission sky coverage







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Gaia status

what happened until now:

- 19.12.2013: launch
- Jan 2014 – arrival at L2
- 1st half of 2014 – commissioning phase
  - Analysis and mitigation of problems
- Jul/Aug 2015 start of nominal operations
- 14.09.2016: release of Gaia DR1 (25.7.2014-16.09.2015)
- Q4 2017 Gaia DR2

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Gaia – data releases

- **Gaia Data Release 1, 14.09.2016 (Data: 25.7.2015-16.09.2015)**
  - **α,δ, G-mag, of ~1.143 billion objects**
  - **Full astrometry for 2 million stars (HIP+TYC2) – TGAS**
  - **Variable star data for RR Lyr and δ-Cephei stars in ecliptic pole fields (LMC)**
- Gaia Data Release 2, Q4 2017
  - 5 par astrometrics for single stars
  - BP/RP integrated photometry
  - RVs for single stars
- Gaia Data Release 3, summer 2018 (tbc)
  - 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

- Gaia Data release 4, summer 2019 (tbc)
  - Variable star classification, epoch photometry
  - Solar system results, preliminary orbital solutions
  - Non-single stars catalogues
- ***Final release, 2022 (tbc)***
  - **Everything!!!!!**

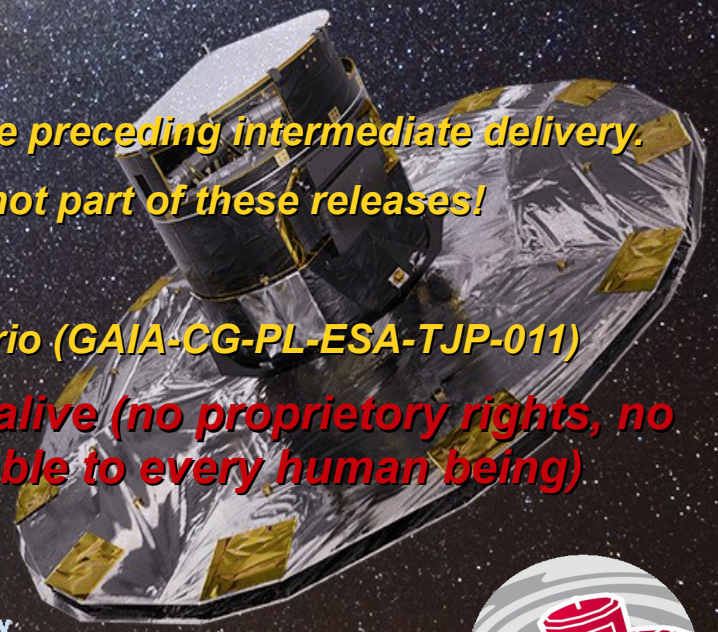
All steps include the a redelivery of the data delivered in the preceding intermediate delivery.

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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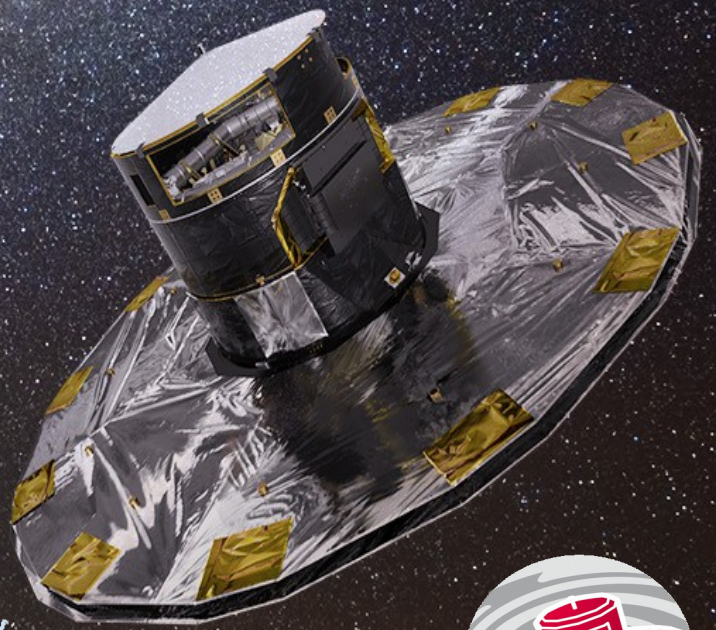
Gaia DR1

- Contents & numbers
- Limitations
- Examples: 2 par astrometry of GBOT data
- Examples: TGAS
-



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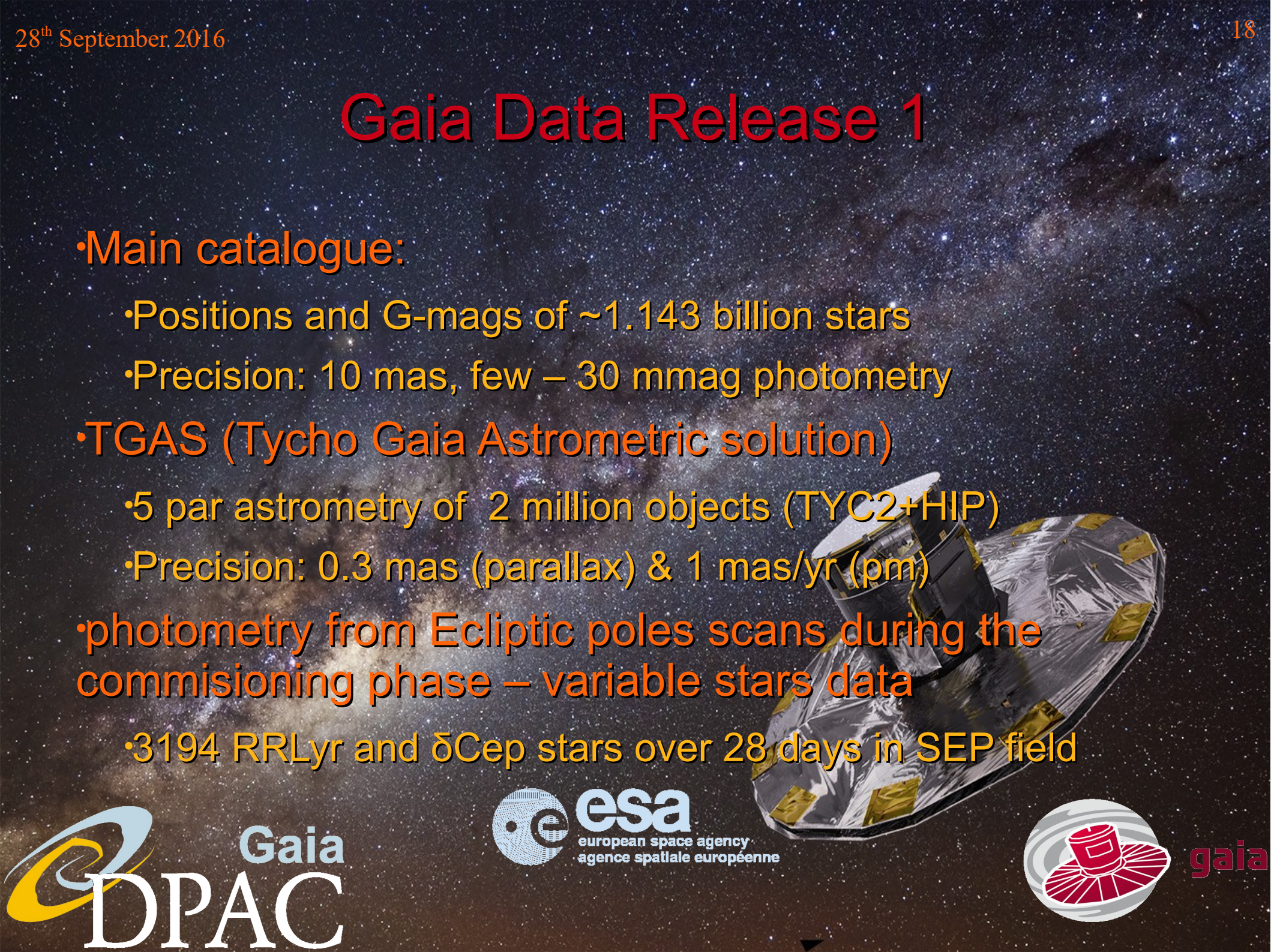
Gaia Data Release 1

- Main catalogue:
  - Positions and G-mags of ~1.143 billion stars
  - Precision: 10 mas, few – 30 mmag photometry
- TGAS (Tycho Gaia Astrometric solution)
  - 5 par astrometry of 2 million objects (TYC2+HIP)
  - Precision: 0.3 mas (parallax) & 1 mas/yr (pm)
- photometry from Ecliptic poles scans during the commisioning phase – variable stars data
  - 3194 RRLyr and δCep stars over 28 days in SEP field



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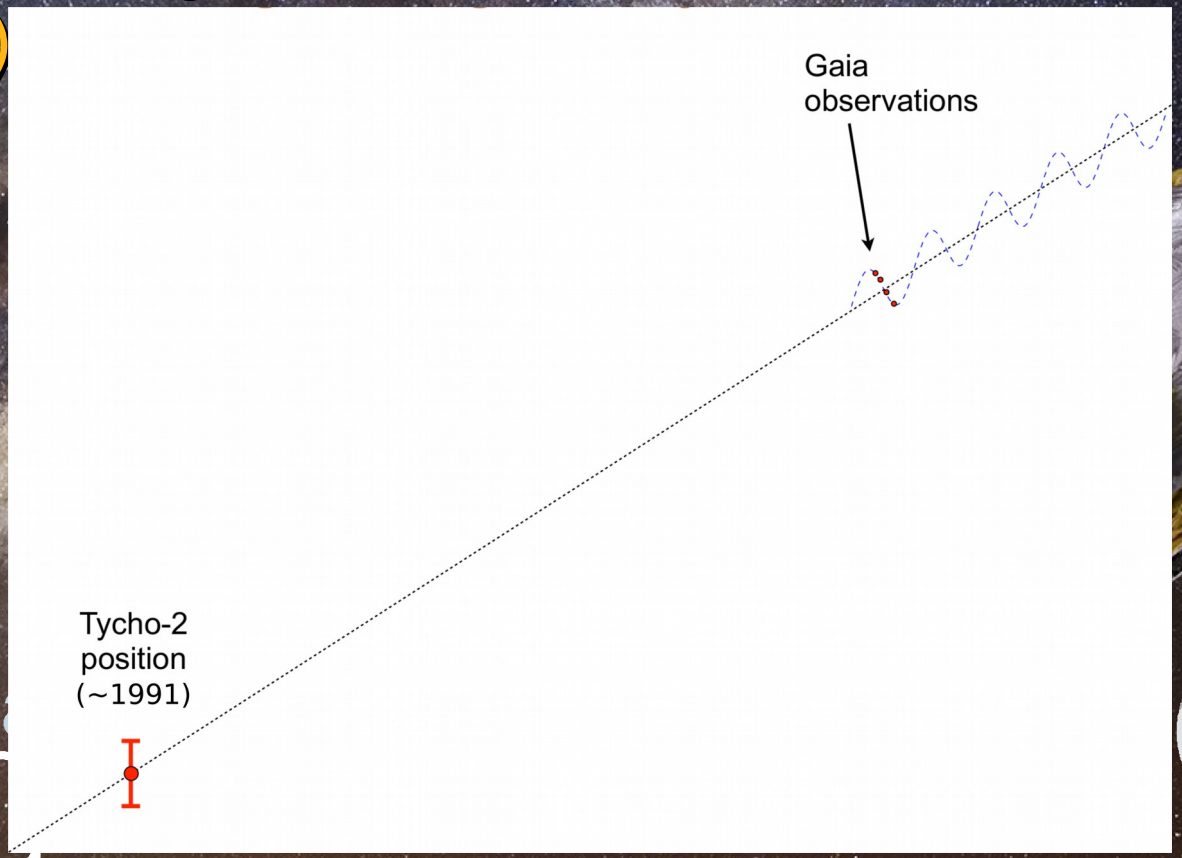
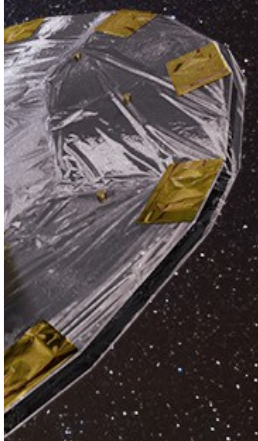
Gaia DR1

- TGAS (Tycho Gaia Astrometric Solution):
  - Time baseline of DR1 too short to disentangle π and μ
  - Tycho2 catalogue, 2.5 million stars G<12 mag (1991.25)

→ TGAS





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Gaia DR1

- TGAS (Tycho Gaia Astrometric Solution):

All sources (2057050 stars)

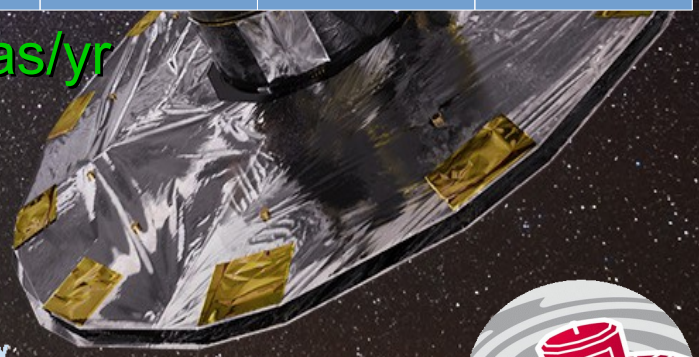
G [mag]	α,δ	π	μ
9	0.2	0.2	0.7
11	0.3	0.3	1.3
12	0.7	0.6	3.2

HIPPARCOS sources (93635 stars)

G [mag]	α,δ	π	μ
7	0.2	0.2	0.04
8.3	0.3	0.3	0.07
9.7	0.7	0.6	0.14

All astrometric uncertainties in mas resp. mas/yr

- **Does not include systematic errors (0.3 mas)**
- **Depends on location on the sky**



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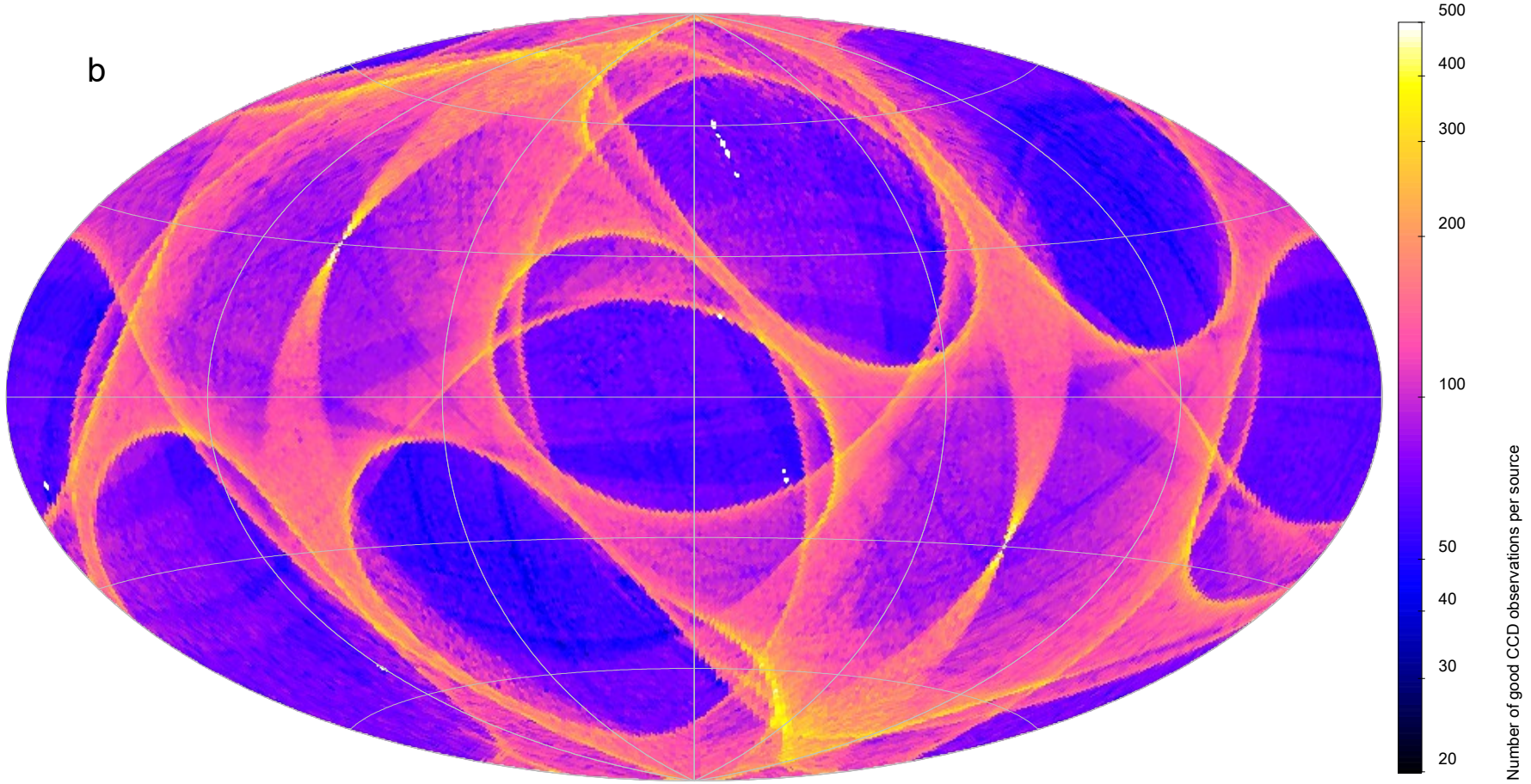
Observations:

Galactic coordinates, Aitoff, *l* = *b* = 0 at center, 0.84 deg^2 cells

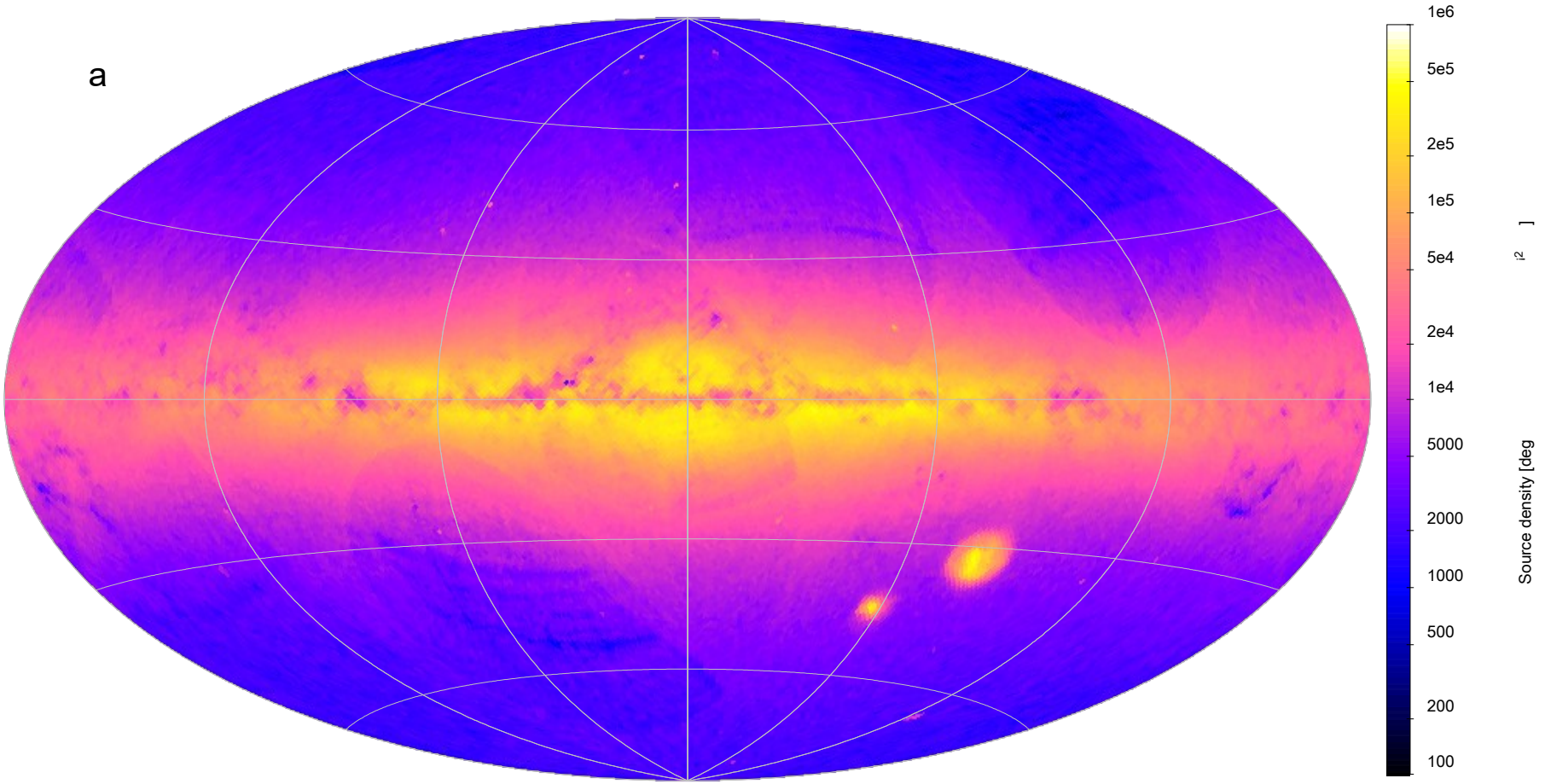


14 (11.8) months of input data. 23 billion focal plane transits.

Secondary set: source density

Galactic coordinates, Aitoff, l = b = 0 at center, 1 deg^2 cells

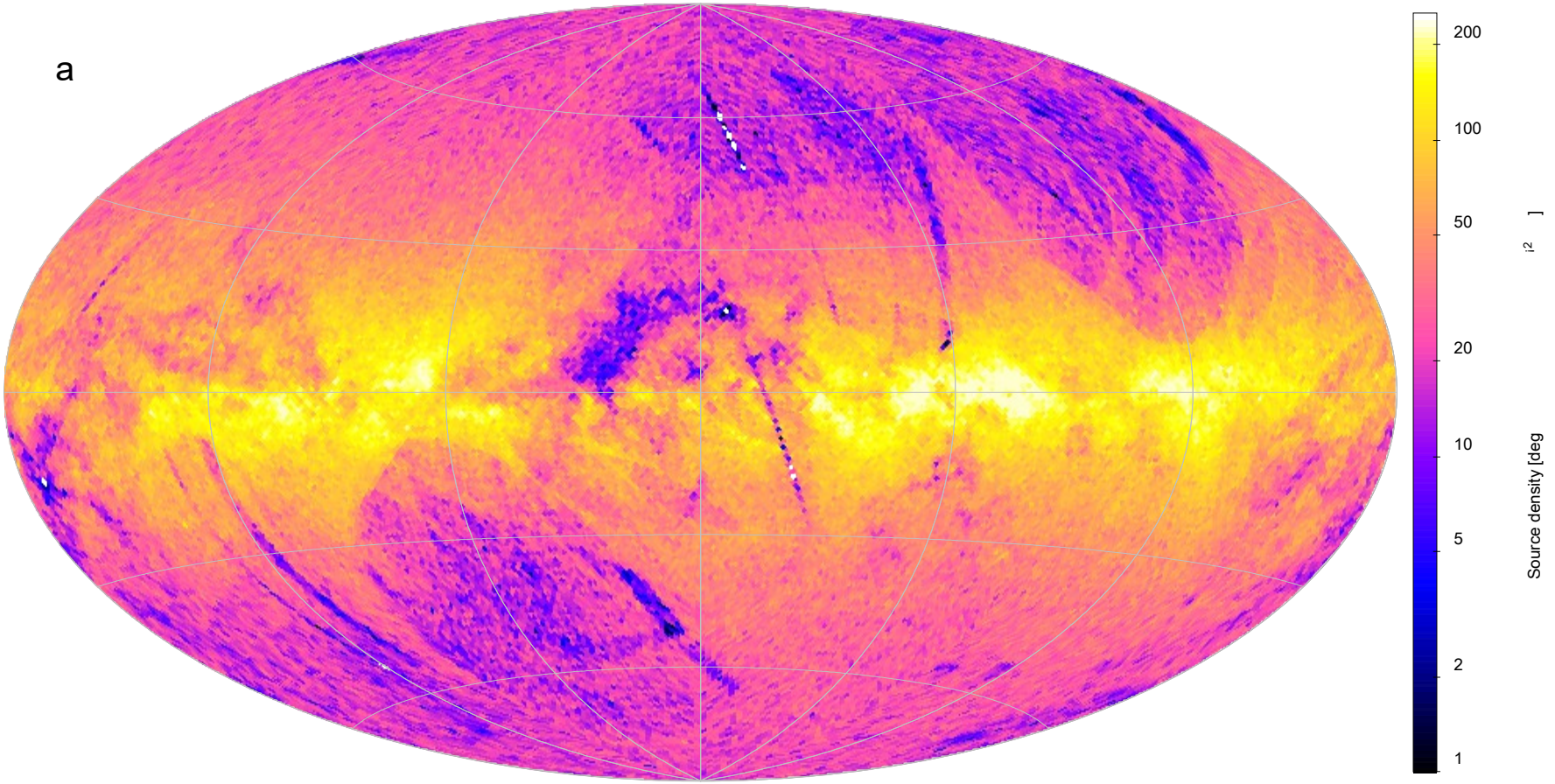
a



1.1 billion sources. 50% with G < 19.07, 90% with G < 20.39

TGAS: source density

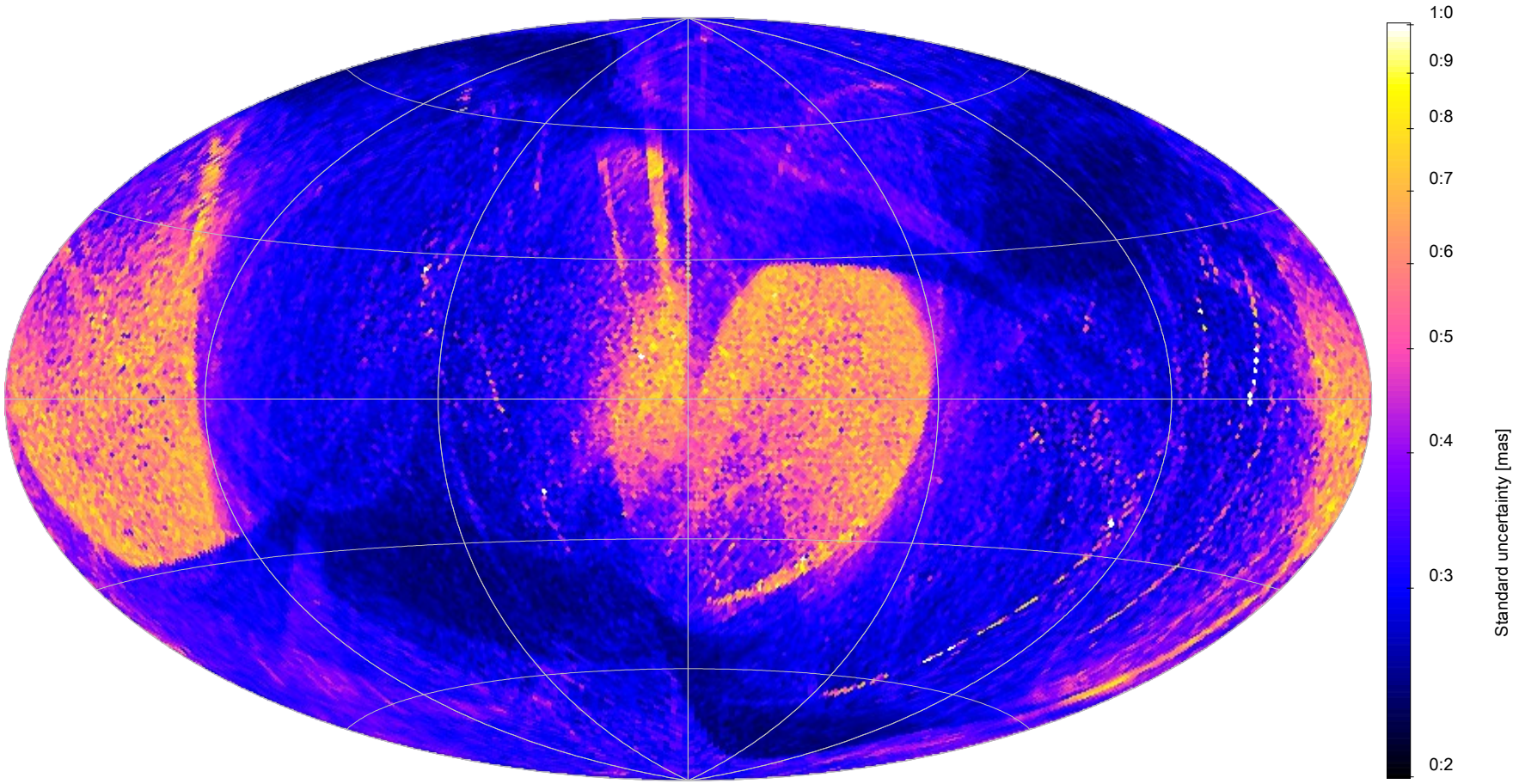
Galactic coordinates, Aitoff, *l* = *b* = 0 at center, 0.84 deg^2 cells



2 million sources. 50% with $G < 11.04$, 90% with $G < 12.05$

TGAS: parallax precisions

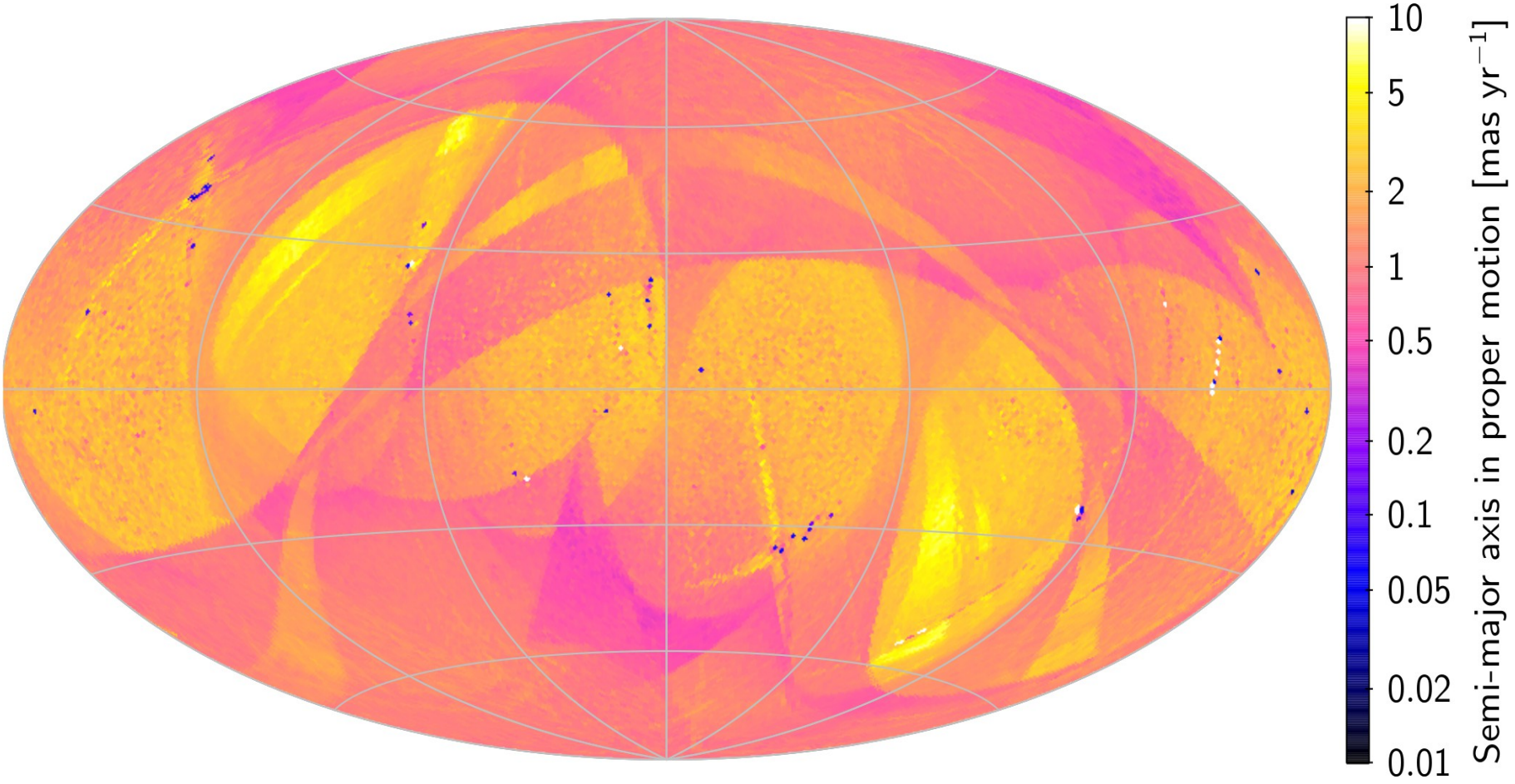
Equatorial coordinates, 0.84 deg^2 cells



2 million sources. 50% with $G < 11.04$, 90% with $G < 12.05$

TGAS: proper motion precisions

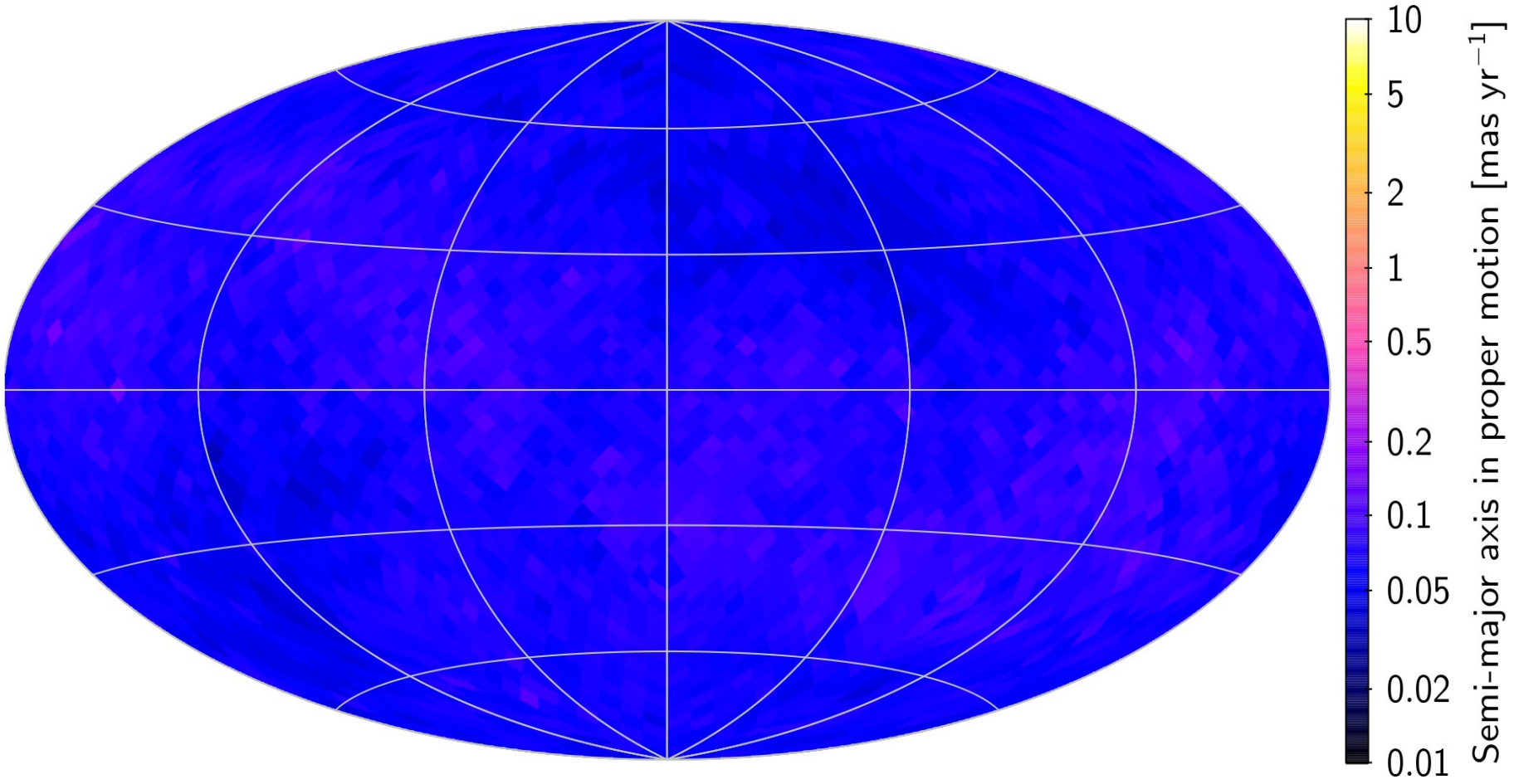
Equatorial coordinates, 0.84 deg^2 cells



2 million sources. 50% with $G < 11.04$, 90% with $G < 12.05$

TGAS: Hipparcos subset PM precisions

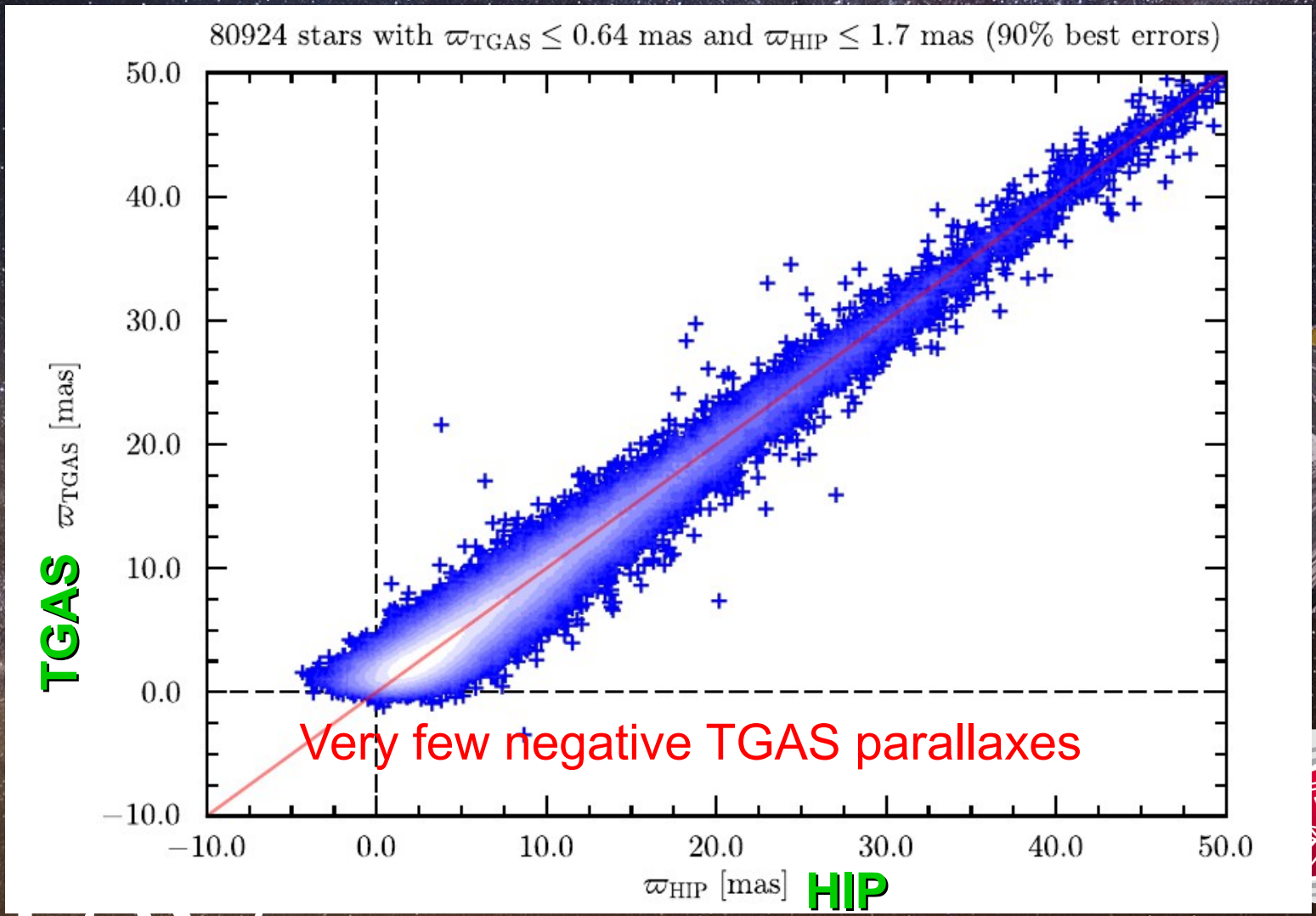
Equatorial coordinates, 0.84 deg ^{2} cells

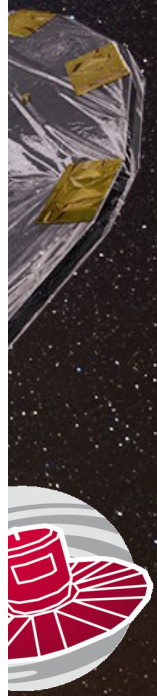


' 94.000 sources. 50% with $G < 8.32$, 90% with $G < 9.73$

Gaia DR1

- TGAS vs. Hipparcos





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Gaia DR1

- Limitations:
  - Short baseline (only 2D astrometry for most stars)
  - Object crossmatch limited by the IGSL and its shortcomings
    - Strict validation process, see talk by Claus Fabricius
  - Hi-pm stars mostly not included (>3500 mas/yr
  - Very red and very blue objects mostly excluded
  - Variable and binary objects
  - Holes
  - Inhomogeneous sky coverage

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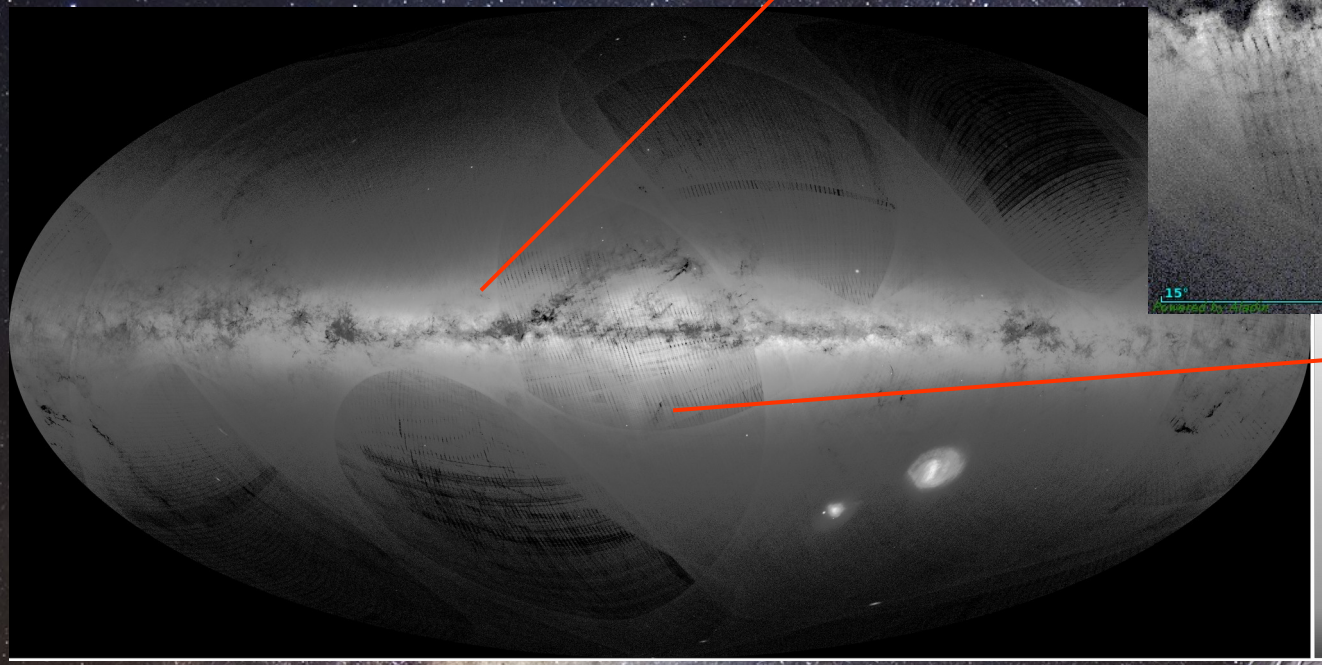
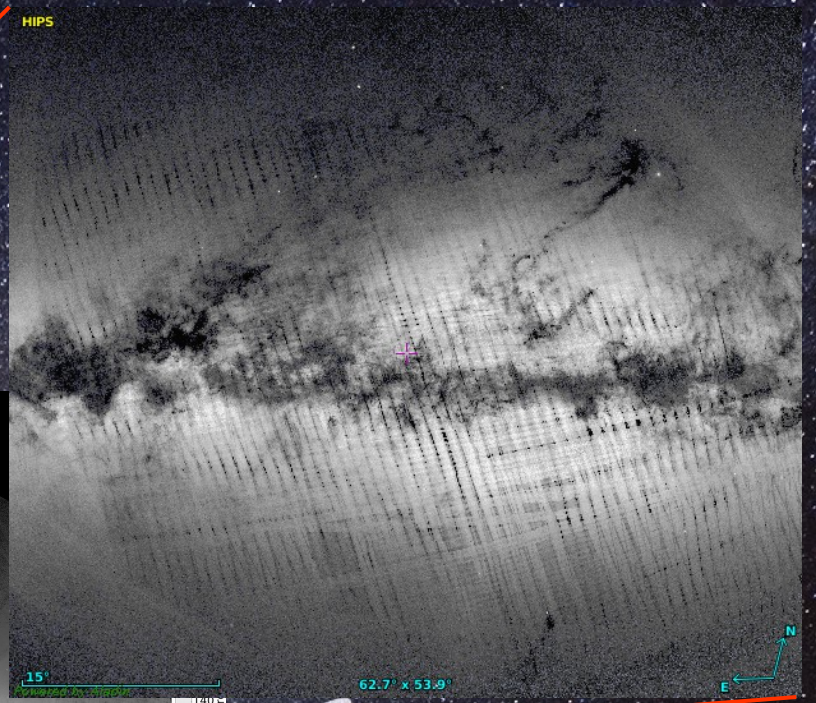
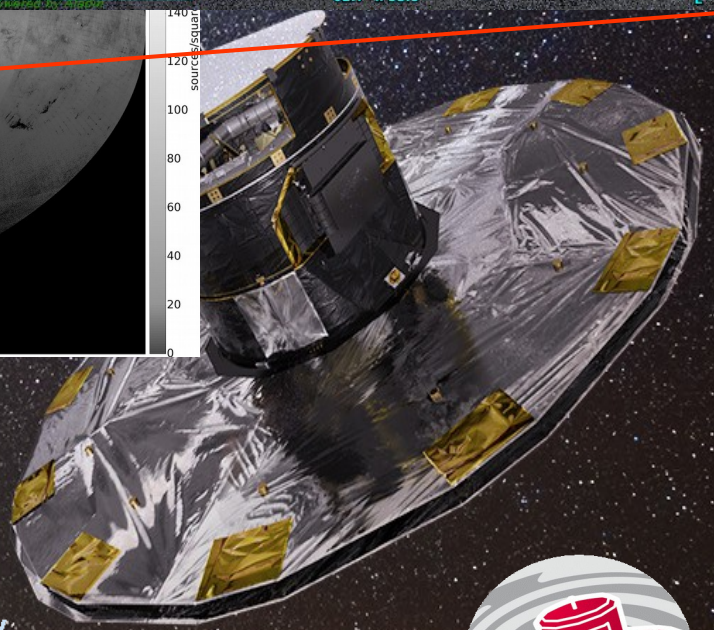
Gaia DR1

- Limitations:







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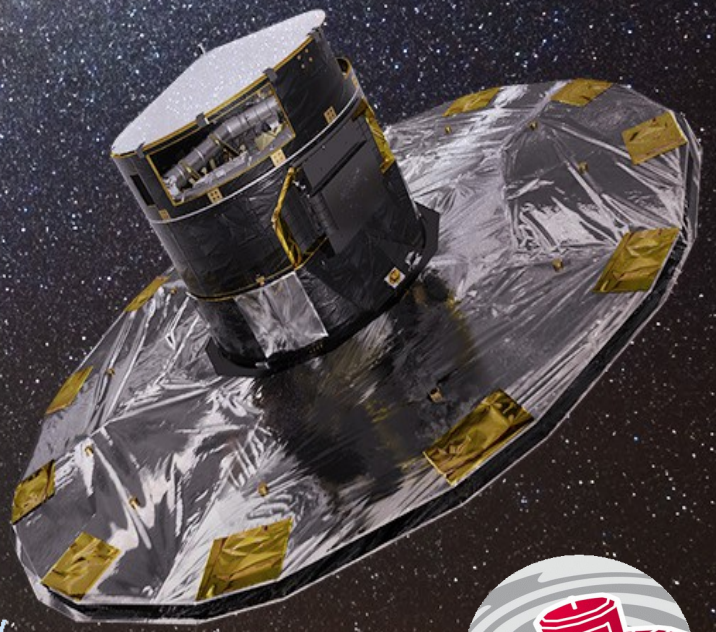
Gaia DR1

- For more information on the validation procedure and numbers, limitations, etc., see talk by Claus Fabricius (tomorrow)



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Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - Ground based astrometric observing programme of the Gaia satellite
  - Orbit recostruction (Calibrate aberration and determination of baselines for solar system object observation)
  - Constraints: 2.5 mm/s & 150 m
  - Astrometric commitment: 20 mas daily
  - Gaia: R~21 mag
  - Contributors: VST, LT, FTN,FTS
  - See also: talk by Sebastien Bouquillon

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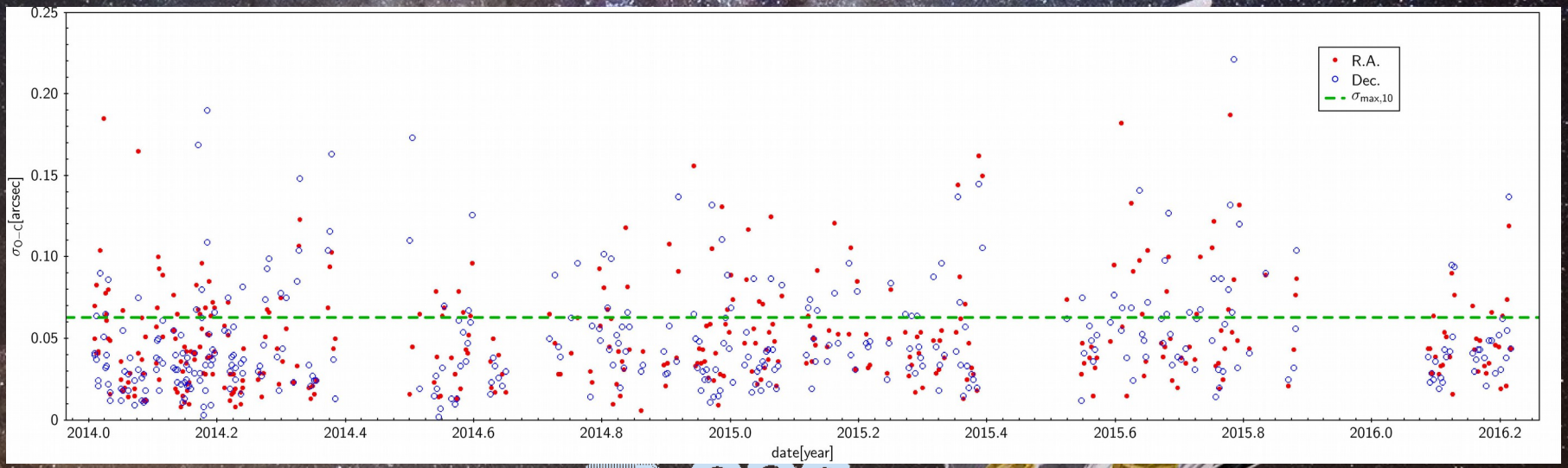
Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - 20 mas precision? Yes! Well, mostly :-)
  - 20 mas accuracy? No, not with current reference material.



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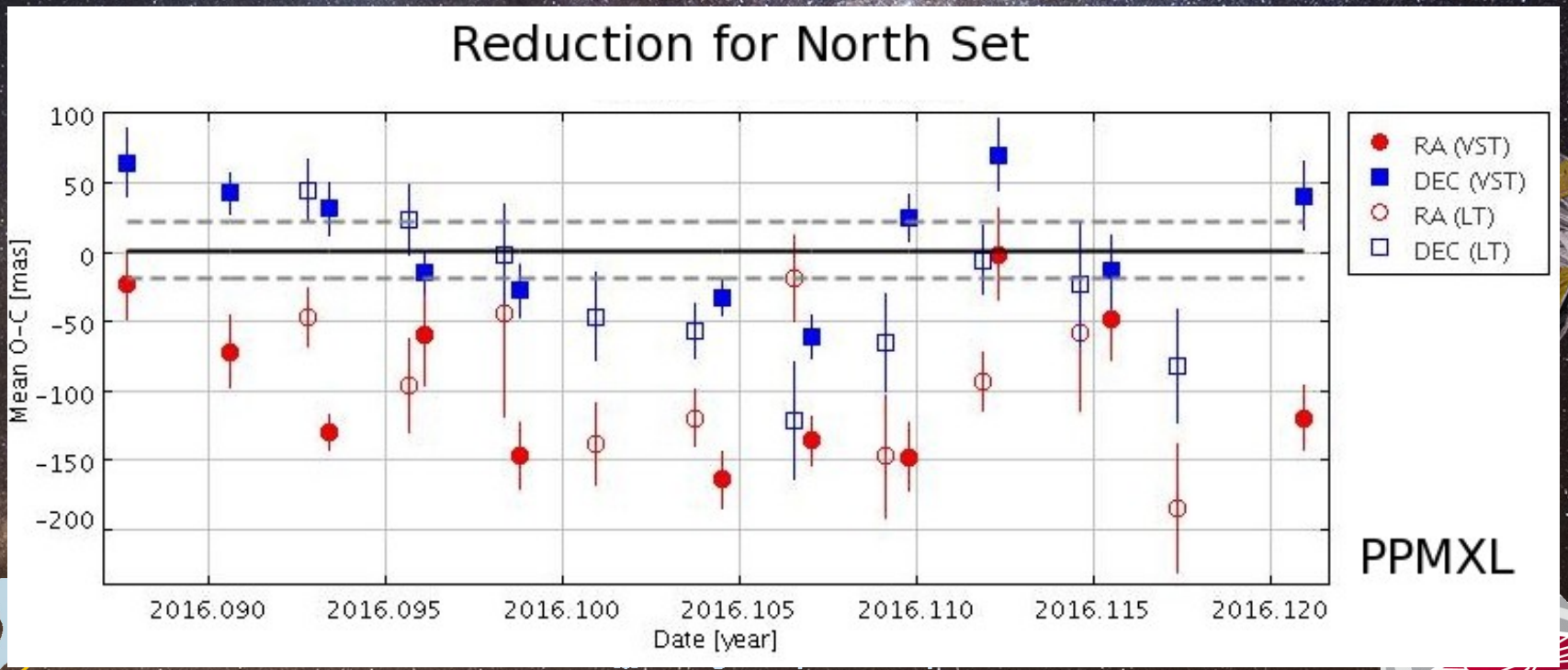
Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - 20 mas accuracy? No, not with current reference material. Example:



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Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - 20 mas accuracy?

...But what happens, when we use Gaia data?

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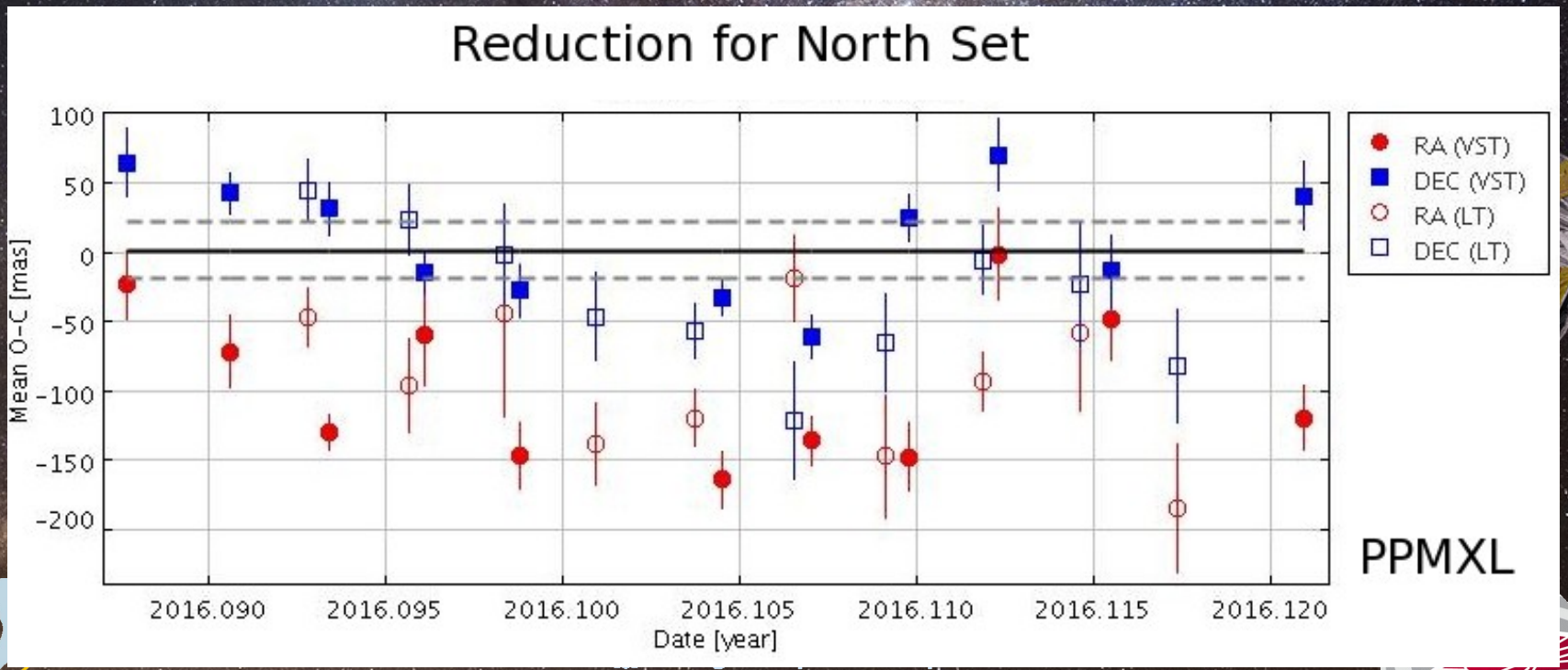
Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - Ground-based reference catalogue (PPMXL):



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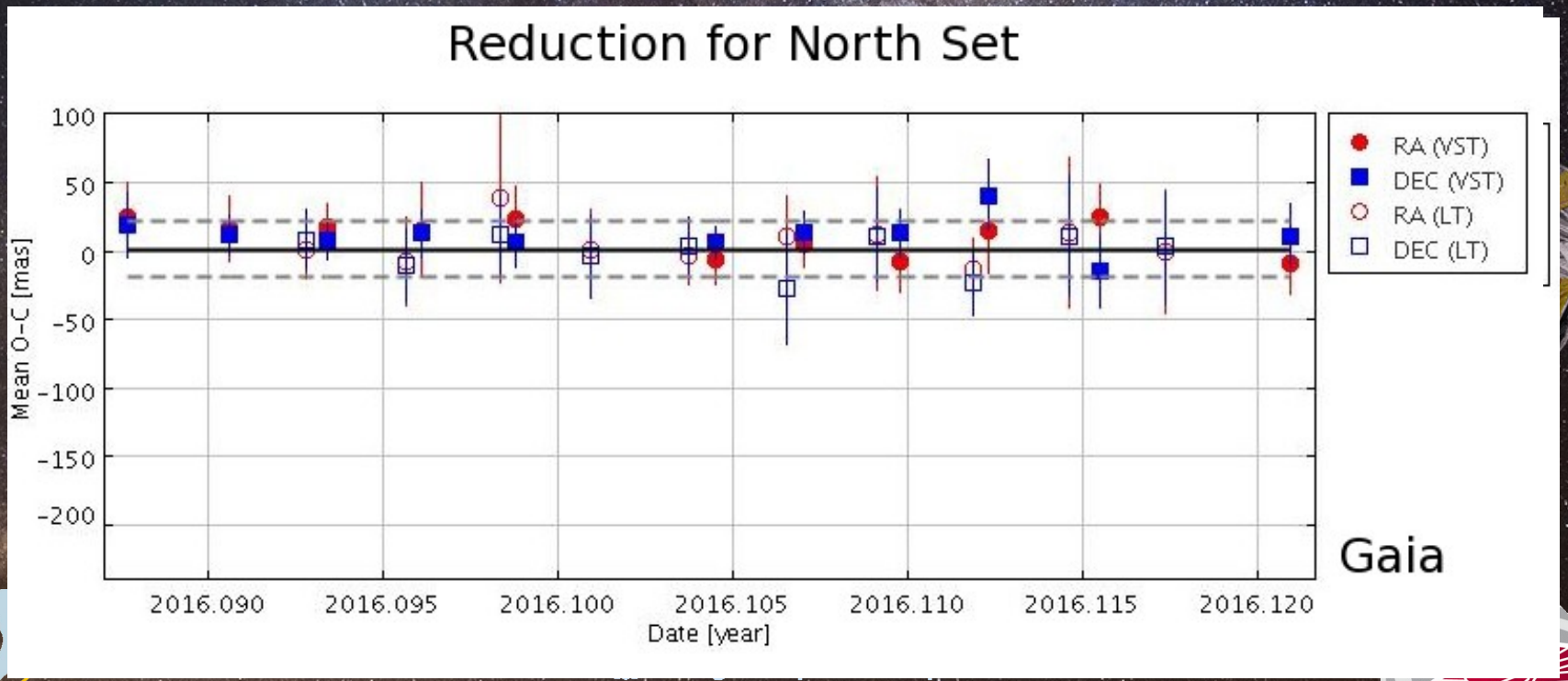
Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - Gaia:



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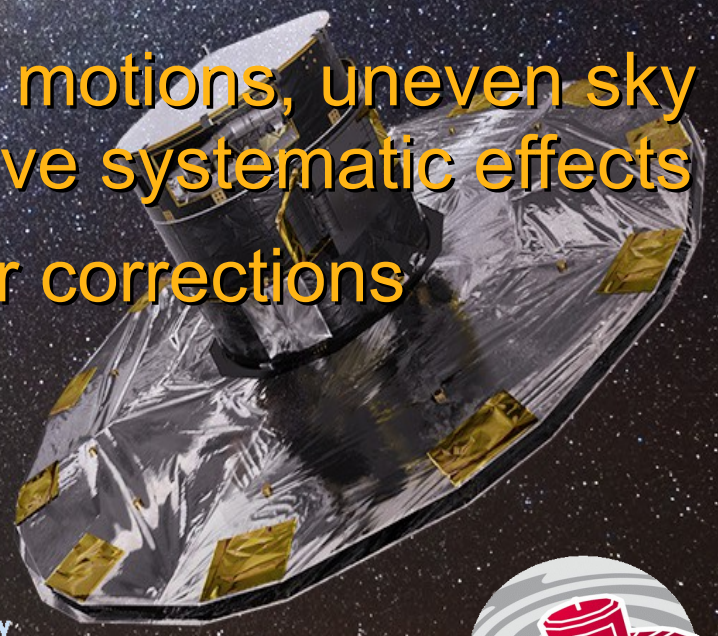
Gaia-DR1: Examples

- GBOT (Ground Based Optical Tracking):
  - Gaia: most systematics collapse!
  - Long term systematics ~30 mas, needs to be analysed
  - DR1: no parallaxes, no proper motions, uneven sky coverage, no colours → will have systematic effects
  - GBOT: optinise DCR and other corrections



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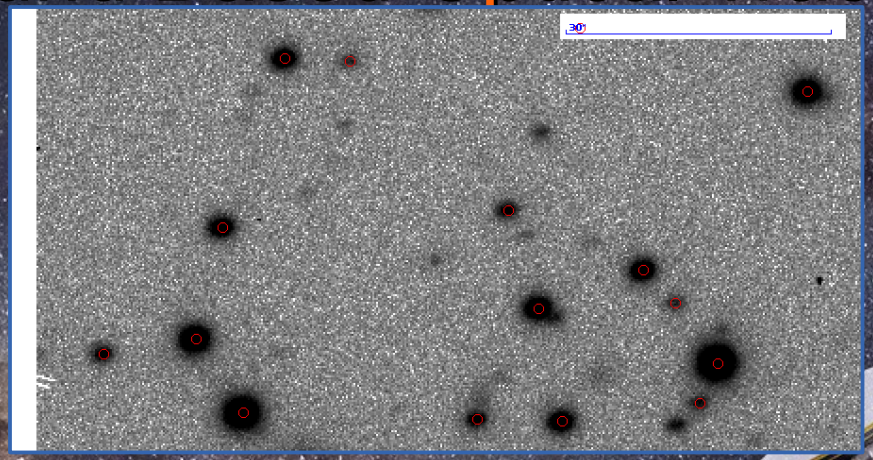
Gaia-DR1: Examples

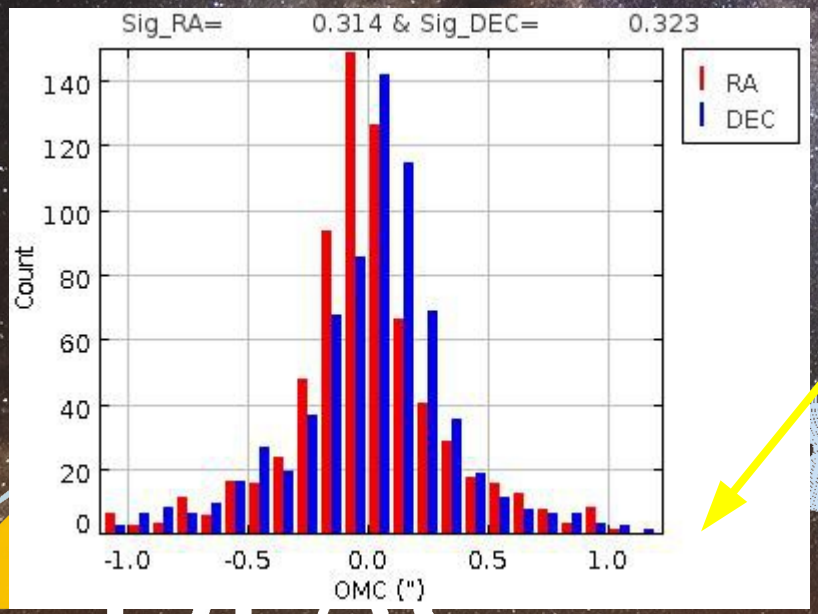
- GBOT (Ground Based Optical Tracking):

VST image:22.07.2014



σ=314 mas

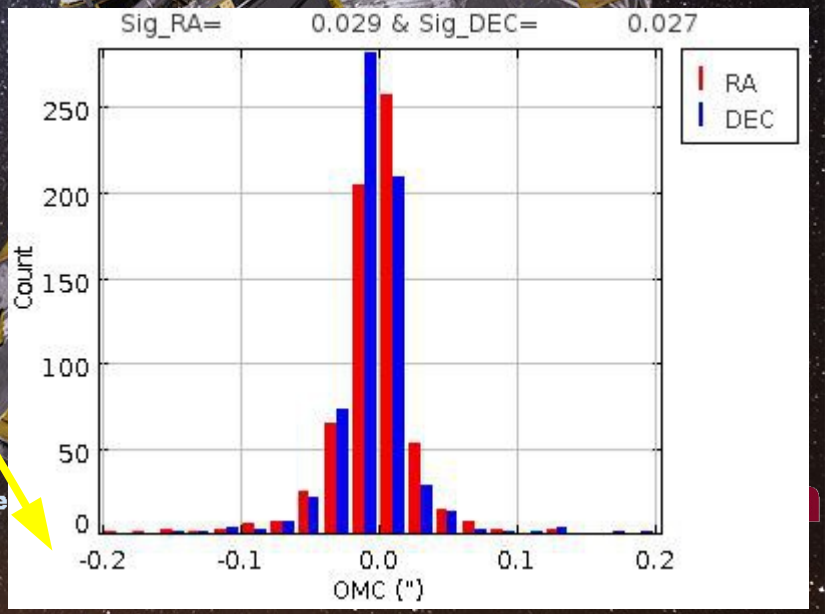
PPMXL



Watch the scale

σ=29 mas

Gaia



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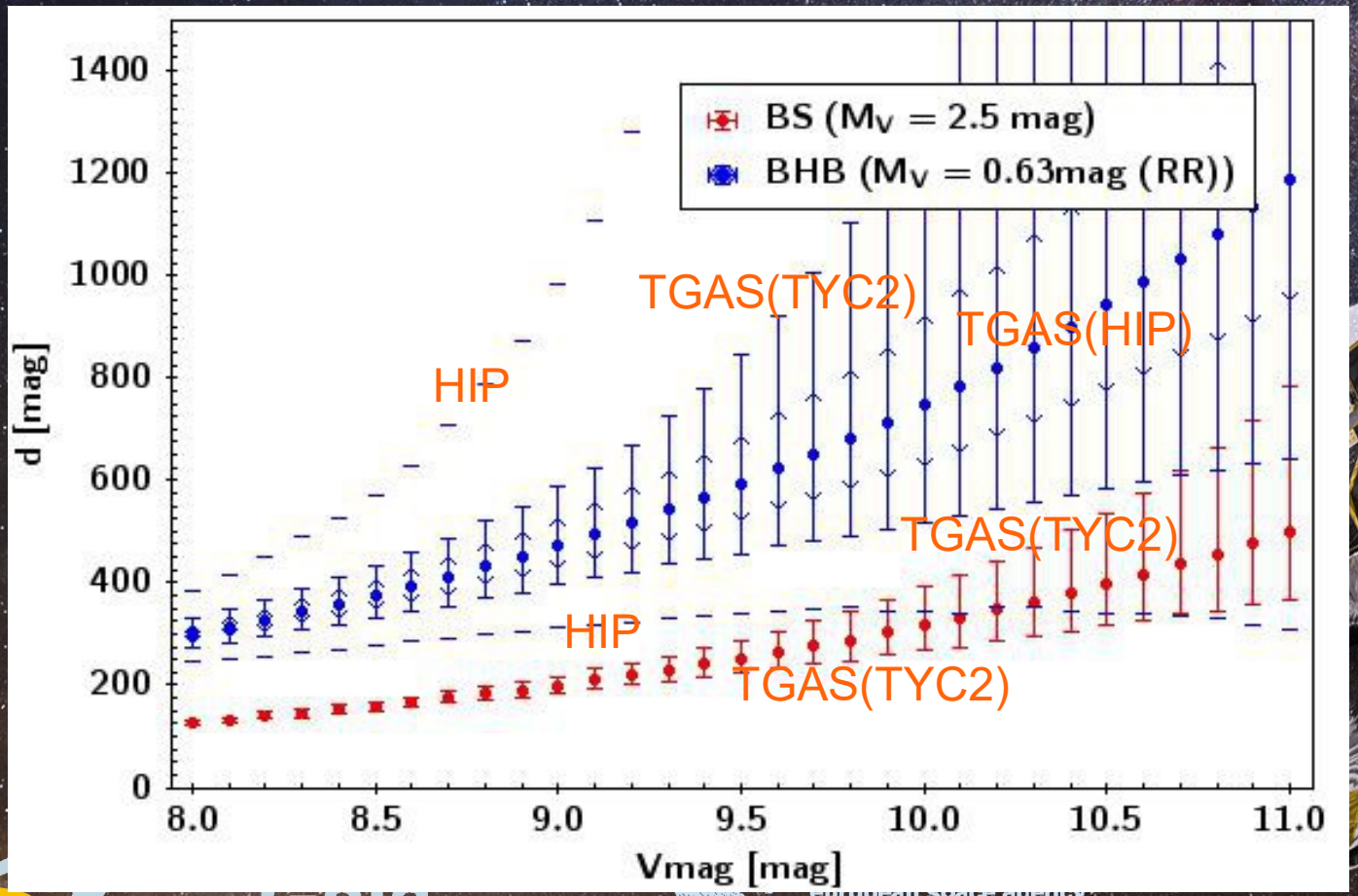
Gaia DR1 - TGAS

- Hipparcos vs. TGAS:

Blue Horizontal Branch stars (BHB): Mv=0.6 mag
Blue Stragglers (BS): 2.5 mag



Based on: Michalik et al. 2015, A&A 574, 115

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Gaia DR1 - TGAS

- Hipparcos vs. TGAS:

Blue Horizontal Branch stars (BHB): Mv=0.6 mag
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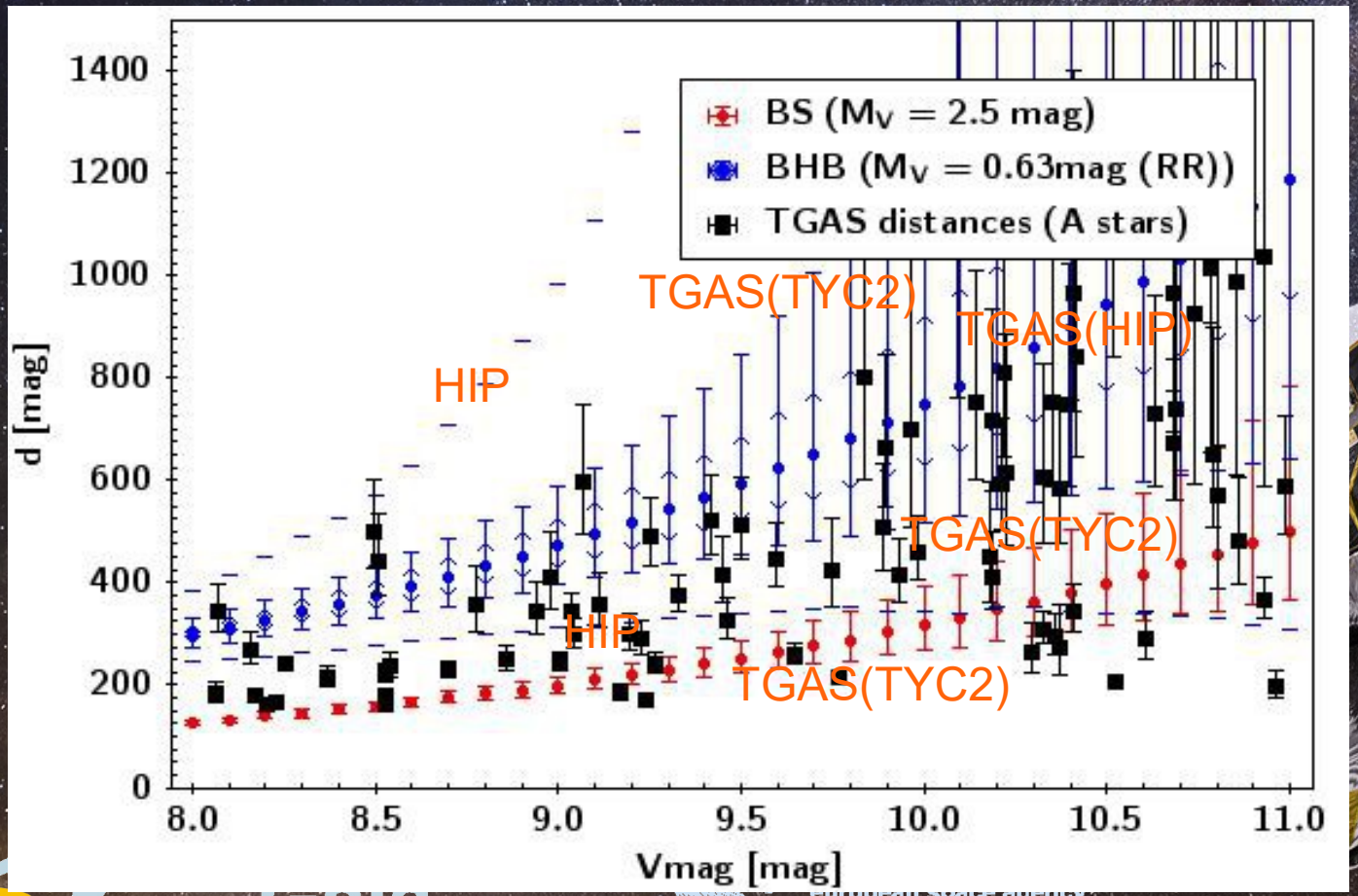

Based on: Michalik et al. 2015, A&A 574, 115

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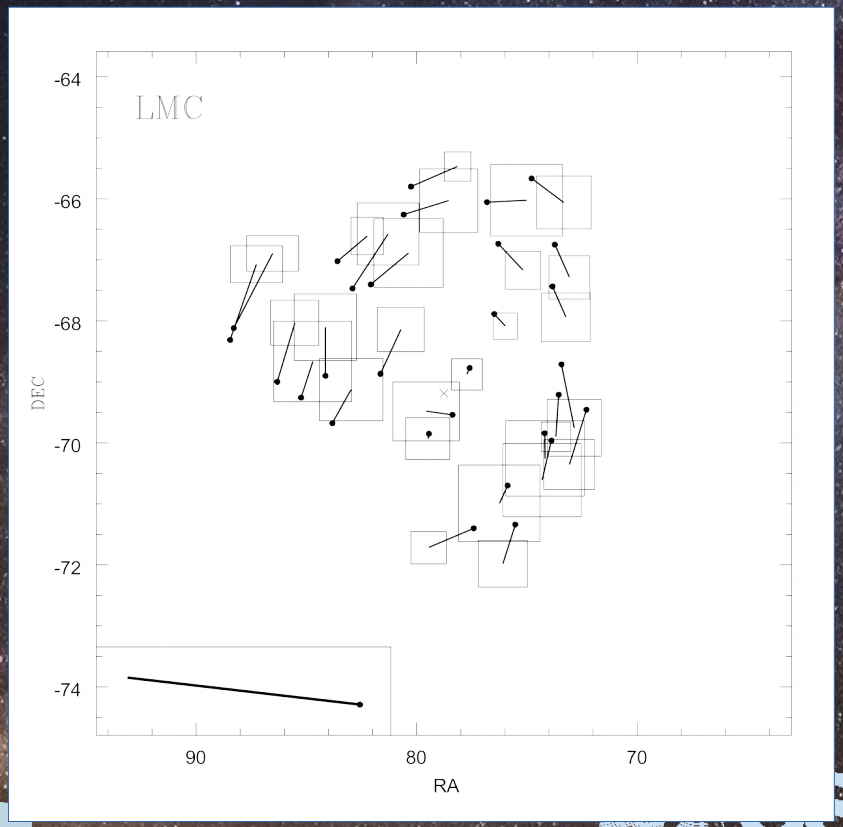
Gaia-DR1:TGAS

- Differential proper motions of the LMC:



Roeland van der Marel (STScI) and Johannes Sahlmann (ESA), submitted to ApJ – current Gaia image of the Week

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Gaia DR1

- How to retrieve it (better: how to extract data from it)
  - Gaia DR1 printed as the Hipparcos catalogue: >50 km bookshelf space!
  - Carefully consider your extraction strategy
  - Best: tap queries using ADQL
  - ADQL workshops in Europe, maybe ADQL workshops in Latin America useful?

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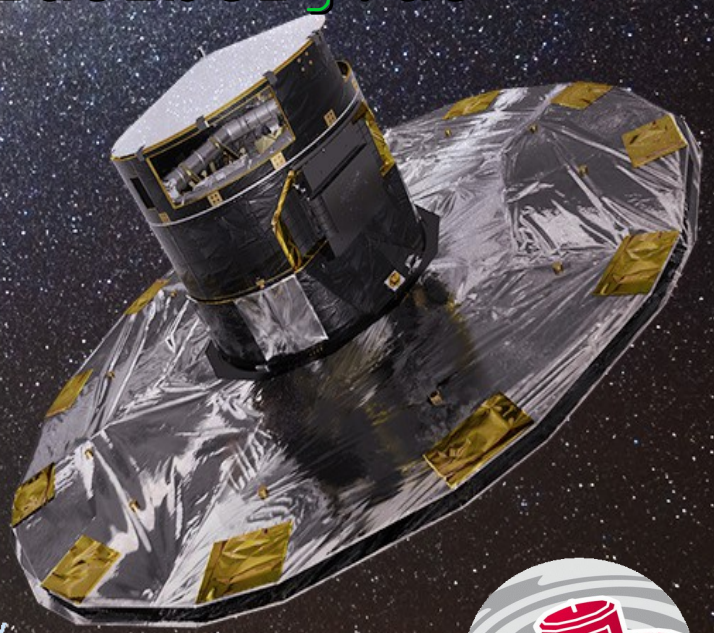
Gaia DR1

- How to retrieve it (better: how to extract data from it)
  - http://archives.esac.esa.int/gaia
  - http://gaia.ari.uni-heidelberg.de
  - And more....
  - CDS: simbad, vizier, etc.



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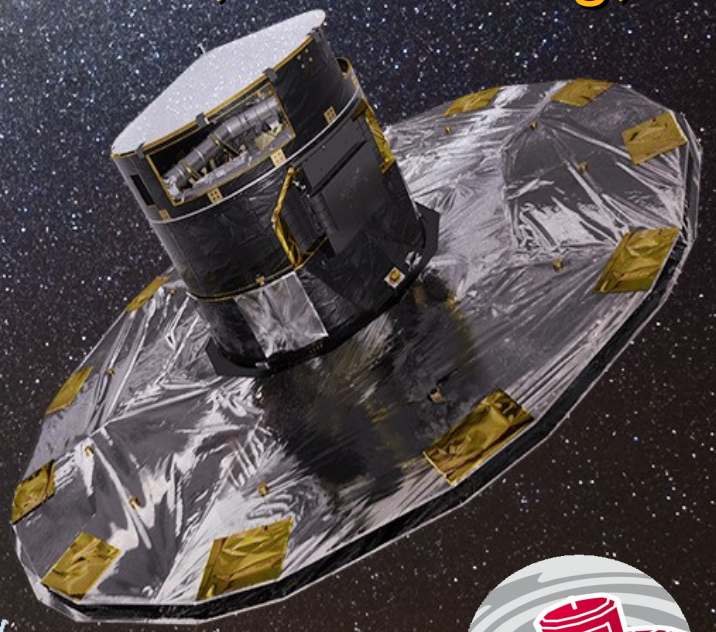
Gaia DR1

- Some Gaia DR1 workshops:
  - Gaia 2016 Data release #1 workshop, 2.-4.11.2016, ESAC, Madrid, Spain
  - Gaia Data workshop, 21.-24.11.2016, Heidelberg, Germany



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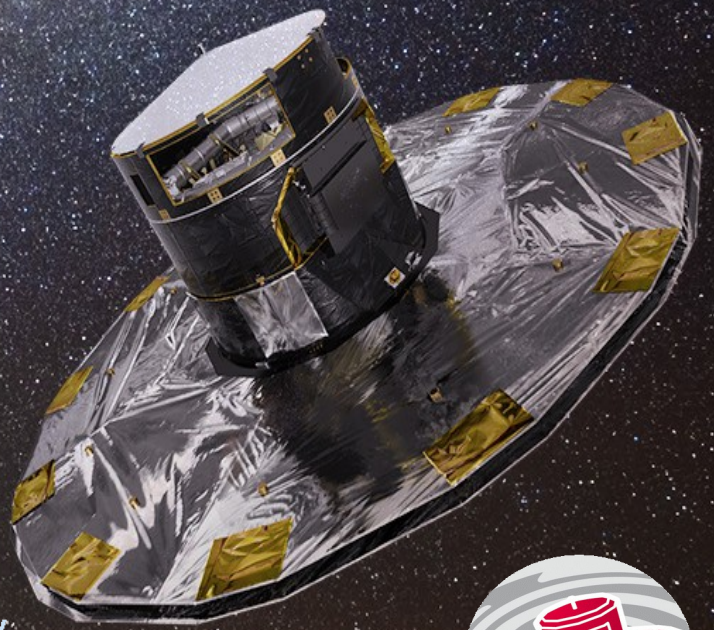
Gaia's final performance

- Data quality
- Examples



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Gaia – performance (final)

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

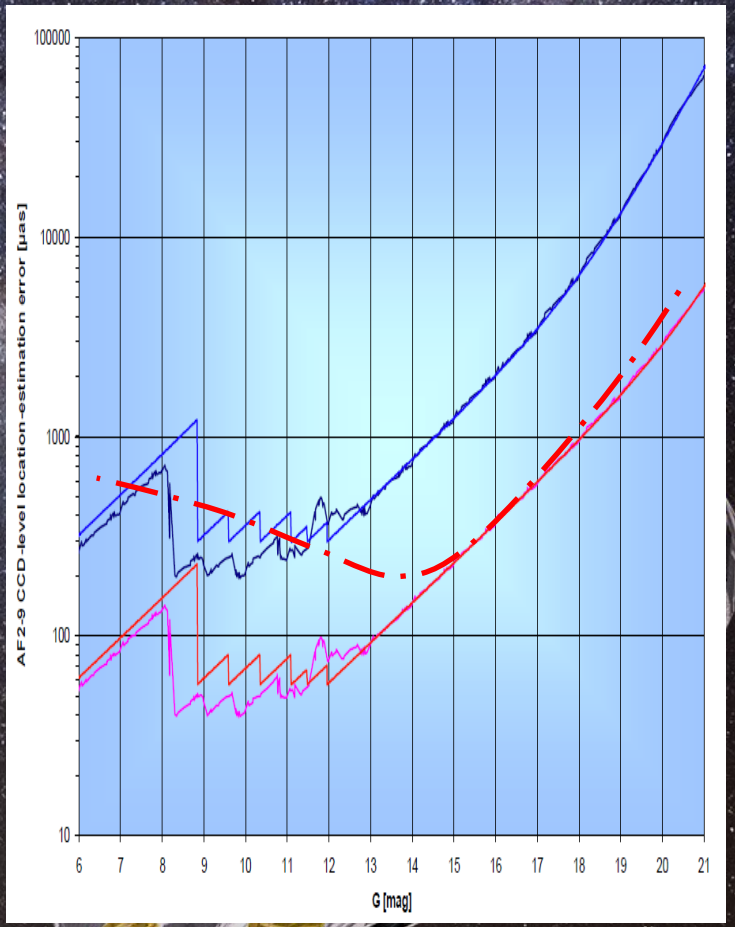
for solar-type stars:

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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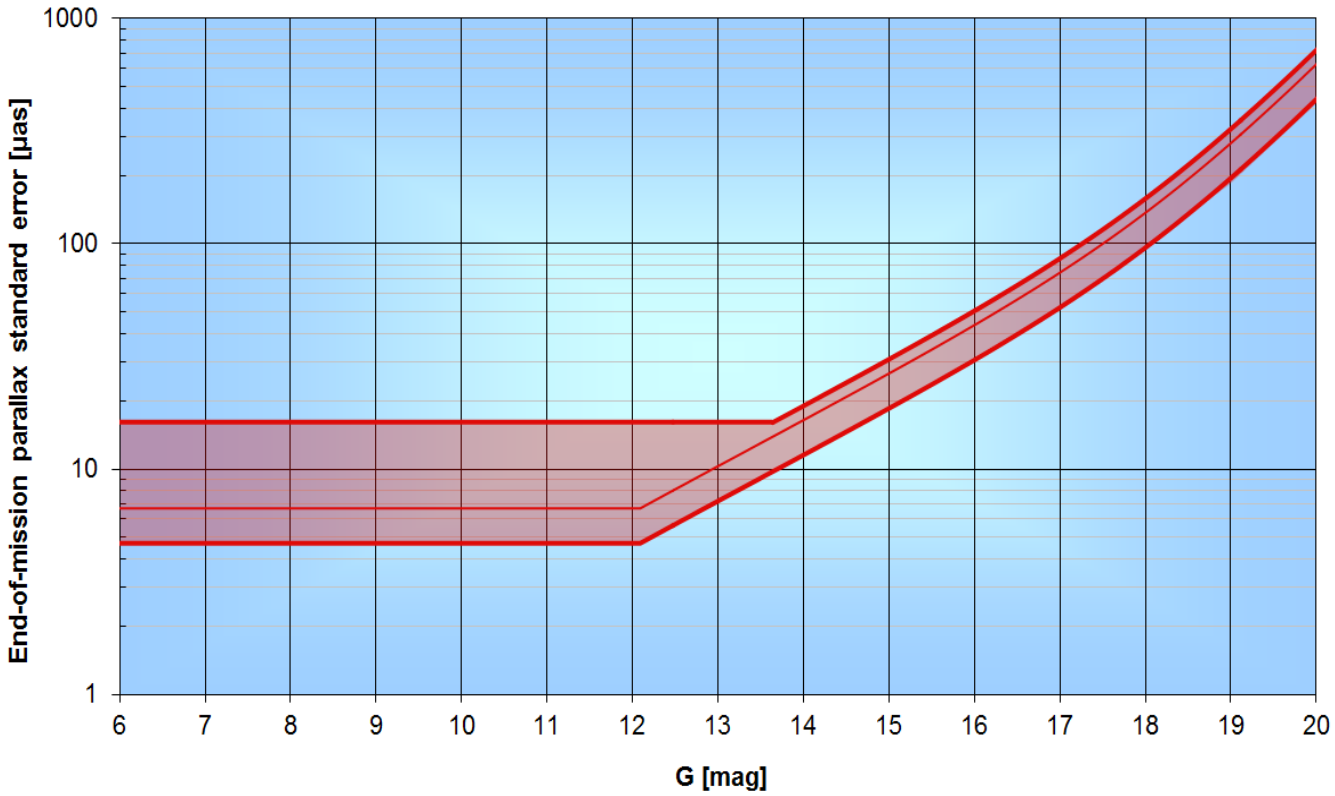
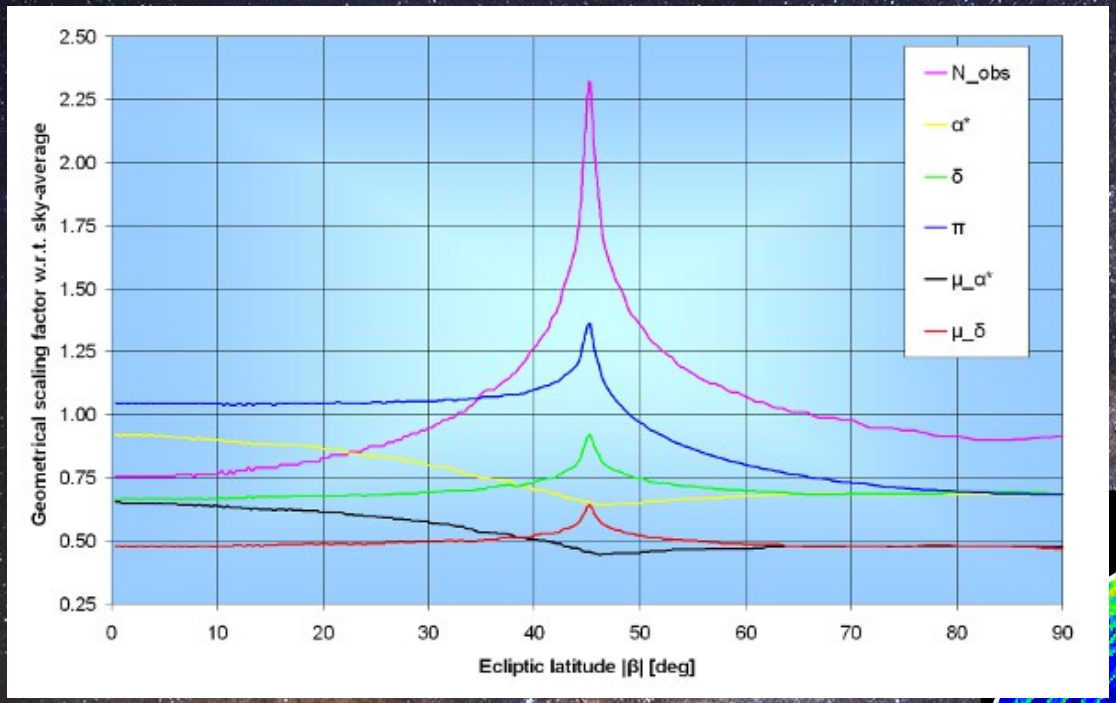
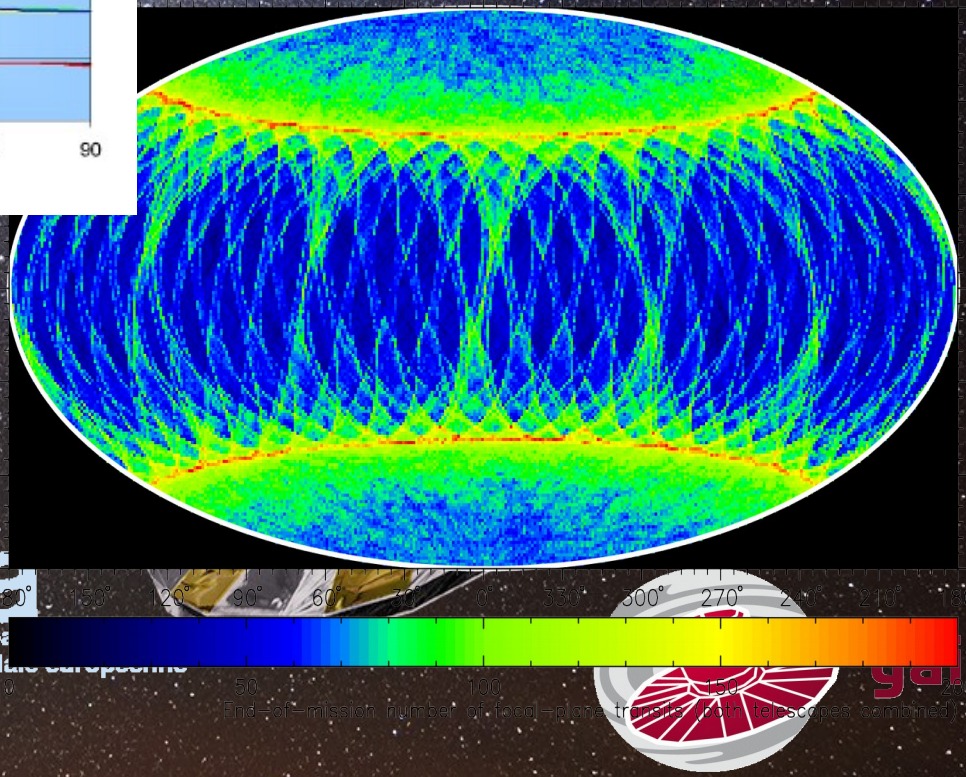
Gaia - performance



Gaia - performance





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Some examples

- 10 bright sdB stars (HIP et al.):

Name	Vmag Mag	μα	δμα	μδ	δμδ	π	δπ	δπ/π	Source
		mas/yr				mas			
HD127493	10.08	-32.9	1.2	-18.2	1.1	5.43	1.21	0.22	HIP07
HD149382	8.94	-6.7	1.8	-4.2	1.8	13.53	1.15	0.08	HIP07
HD205805	10.18	+75.5	1.2	-10.0	0.9	3.75	1.68	0.45	HIP07
HD188112	10.22	+34.4	2.1	+21.6	1.4	13.64	1.71	0.12	HIP07
CD -38 222	10.26	+46.0	1.7	-6.5	1.1	2.09	1.52	0.73	HIP07
HD4539	10.29	+5.1	1.8	+25.2	1.4	2.22	2.17	0.98	HIP07
Feige66	10.59	+3.0	1.7	-26.0	1.3	6.15	1.62	0.26	HIP07
HD171858	9.85	-13.9	1.6	-22.7	1.6	----	----	----	TYC2
SB707	11.90	+85.8	3.2	-48.2	2.3	3.49	3.71	1.06	HIP07
SB815	11.00	-19.8	1.5	-7.5	1.8	4.56	1.72	0.38	HIP07

HIP07 = van Leeuwen, F., 2007, A&A 474,655; TYC2 = Høg et al., 2000, A&A 355, 27

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Some examples

- 10 bright sdB stars (HIP et al. with Gaia errors):

Name	Vmag Mag	μα	δμα	μδ	δμδ	π	δπ	δπ/π	Source
		mas/yr				mas			
HD127493	10.08	-32.9	1.2	-18.2	1.1	5.43	0.016	0.003	HIP07
HD149382	8.94	-6.7	1.8	-4.2	1.8	13.53	0.016	0.001	HIP07
HD205805	10.18	+75.5	1.2	-10.0	0.9	3.75	0.016	0.004	HIP07
HD188112	10.22	+34.4	2.1	+21.6	1.4	13.64	0.016	0.001	HIP07
CD -38 222	10.26	+46.0	1.7	-6.5	1.1	2.09	0.016	0.008	HIP07
HD4539	10.29	+5.1	1.8	+25.2	1.4	2.22	0.016	0.007	HIP07
Feige66	10.59	+3.0	1.7	-26.0	1.3	6.15	0.016	0.003	HIP07
HD171858	9.85	-13.9	1.6	-22.7	1.6	----	0.016	----	TYC2
SB707	11.90	+85.8	3.2	-48.2	2.3	3.49	0.016	0.005	HIP07
SB815	11.00	-19.8	1.5	-7.5	1.8	4.56	0.016	0.004	HIP07

HIP07 = van Leeuwen, F., 2007, A&A 474,655; TYC2 = Høg et al., 2000, A&A 355, 27

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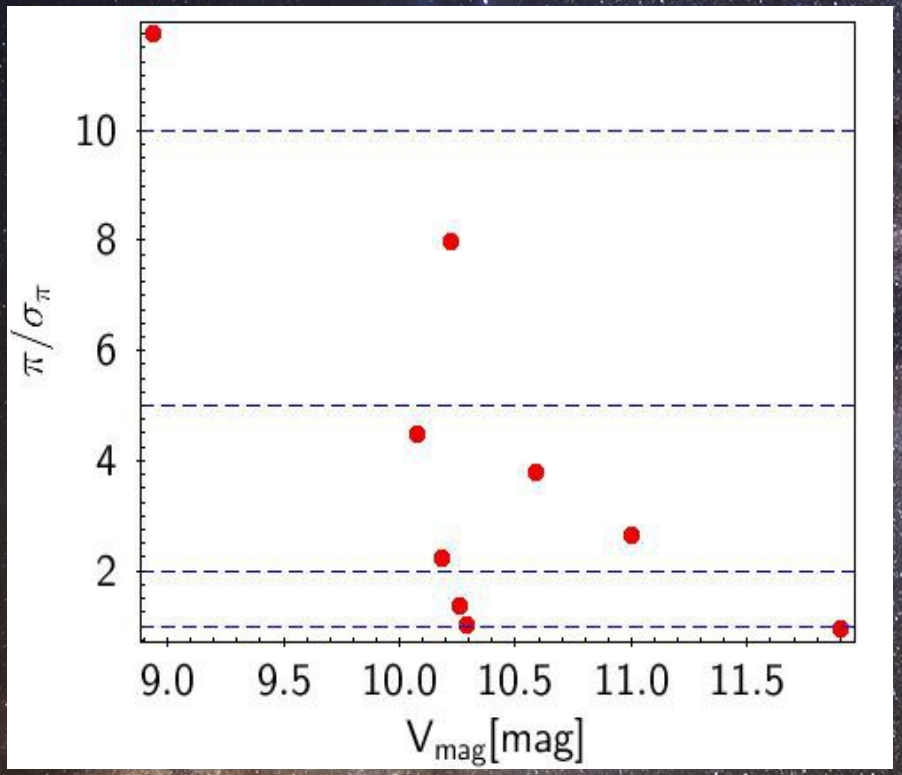
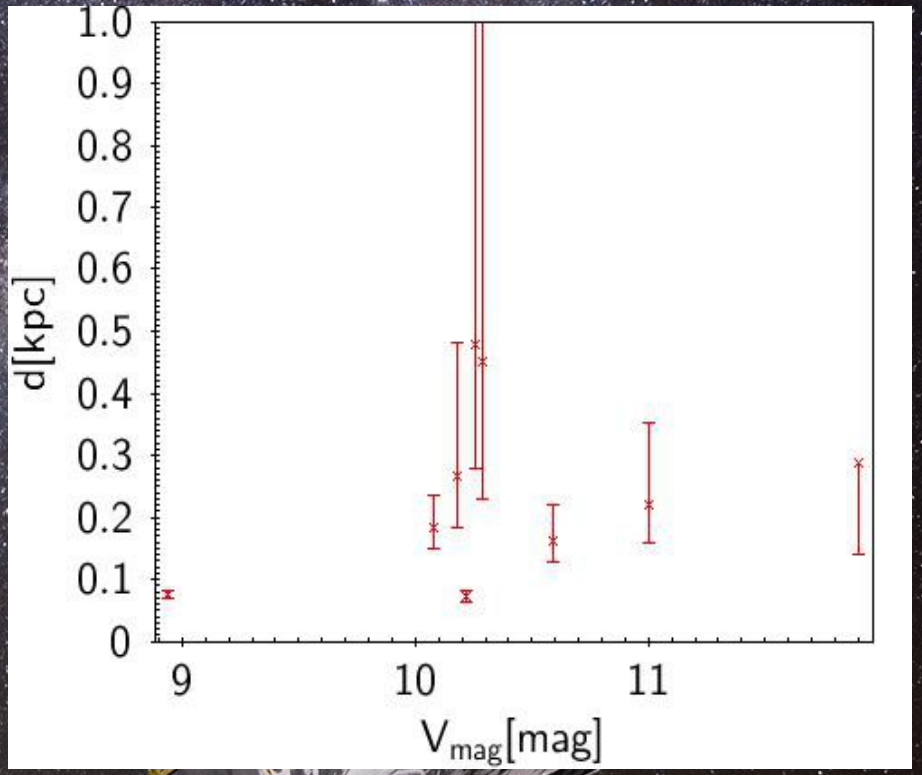
Some examples

- 10 bright sdB stars:





Some examples

- Parallaxes of a typical Sun-like star (M_G=5 mag):

d [pc]	G [mag]	π[μas]	σπ[μas]	σπ/π
100	10	10,000	16	0.0016
200	11.5	5,000	16	0.0032
500	13.5	2,000	16	0.0080
1000	15.0	1,000	28	0.0280
2000	16.5	500	60	0.3000
5000	18.5	200	200	1.0000
10000	20.0	100	500	5.0000

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Some examples

- HIP&homegrown proper motion quality for a typical Sun-like star (M_G=5 mag):

d [pc]	G [mag]	σμ[μas/yr]	δv_{tan} [km/s]
100	10	1000	0.47 (2.4)
200	11.5	1500	1.4 (4.8)
500	13.5	2000	4.7 (12)
1 000	15.0	5000	12.0
2000	16.5	5000	48
5000	18.5	10000	240
10000	20.0	20000	1000

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Some examples

- Gaia Proper motion quality for a typical Sun-like star (M_G=5 mag):

d [pc]	G [mag]	σμ[μas/yr]	δv_{tan} [km/s]
100	10	16	0.008
200	11.5	16	0.015
500	13.5	16	0.031
1000	15.0	28	0.133
2000	16.5	60	0.570
5000	18.5	200	11.8
10000	20.0	500	23.7

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Some examples

- HD 271791 and its origin, see Heber et al. 2008
  - B2-3III HVS star
  - v_{rad}=441 km/s,
  - d=21±4 kpc
  - V=12.25 mag
  - Parallax of 21 kpc: 0.048 mas = 48 μmas
  - Error: 16 μmas → $d=21^{+10}_{-6}$ kpc

→ not better than before (but improvements of models, based on similar stars?)

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Some examples

- HD 271791 and its origin, see Heber et al. 2008
  - B2-3III HVS star
  - v_{rad}=441 km/s,
  - d=21±4 kpc
  - V=12.25 mag
  - Error of proper motions (Gaia): 16 μas/yr = 1.6 km/s
  - Before (3-5 mas/yr, based on scatter): 300-500 km/s

→ drastic improvement!

Star unfortunately not in TGAS/DR1

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Further information and resources

Gaia webpage at ESA (lots of information and outreach material:

http://www.cosmos.esa.int/gaia

Gaia release scenario:

http://www.cosmos.esa.int/gaia/releases

Youtube movie about Inter-DPAC convention, Leiden (NL), Nov. 2015

https://youtu.be/E9GYLcesPp0

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Gaia – acknowledgements

- Uli Bastian, Michael Biermann, Sebastien Bouquillon & Stefan Jordan for plots, discussions, clarifications, information, etc.
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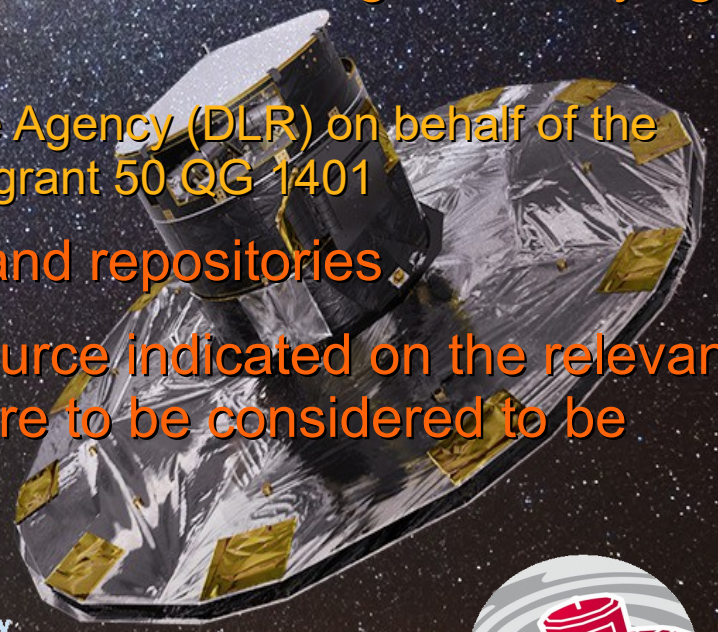
- Various other DPAC members for plots, etc.
- ESA, DPAC, and the national funding agencies for funding and carrying out the mission
  - This work was supported by the German Space Agency (DLR) on behalf of the German Ministry of Economy & Technology via grant 50 QG 1401
- CDS, ADS and other public data archives and repositories
- Figures and pictures are courtesy of the source indicated on the relevant pages, and if there is no source info, they are to be considered to be courtesy to ESA.



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