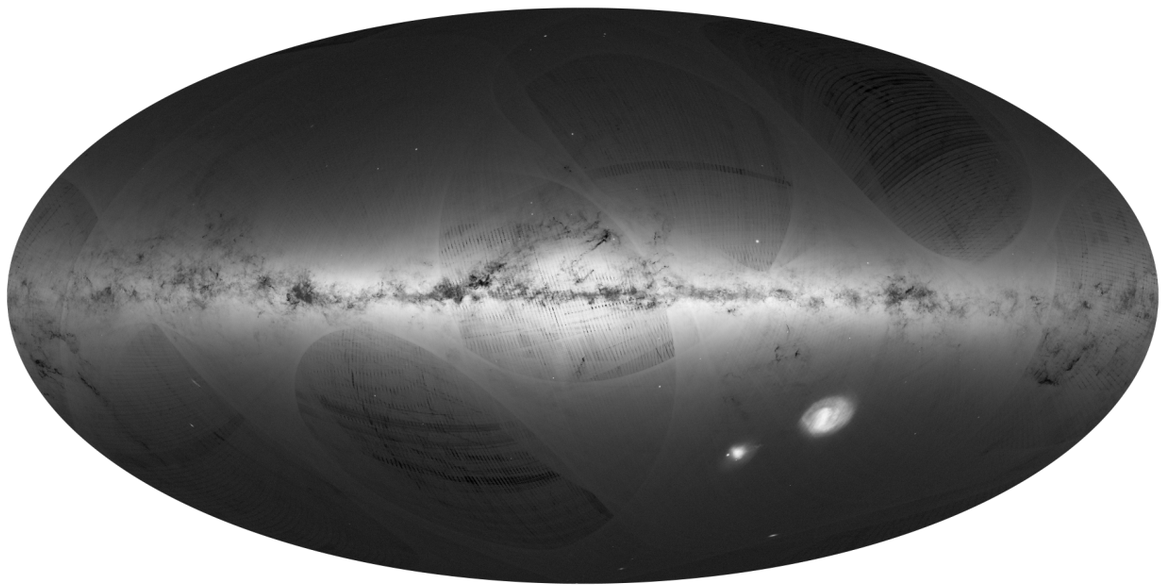
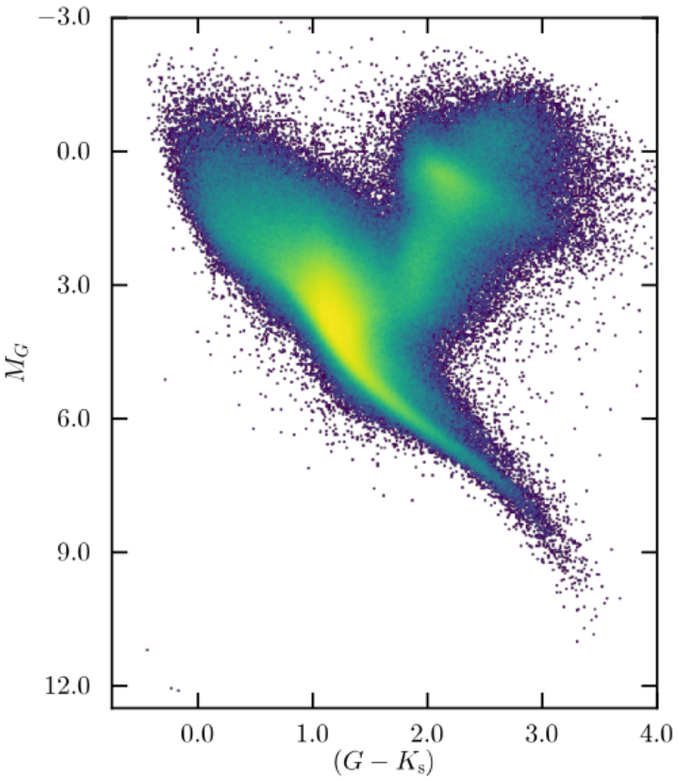
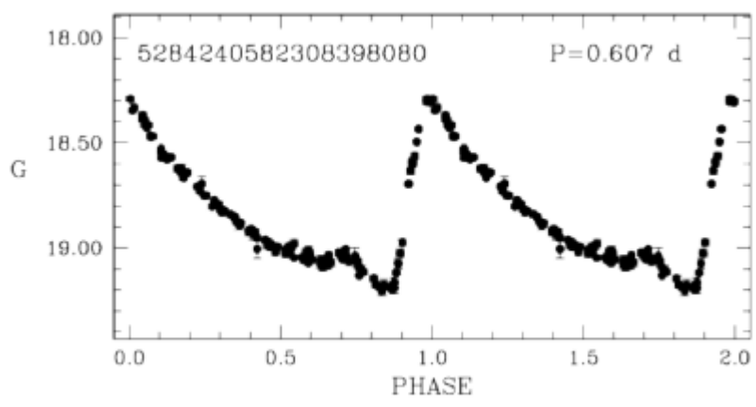
Gaia DR1

Carine Babusiaux

l'Observatoire de Paris — GEPI



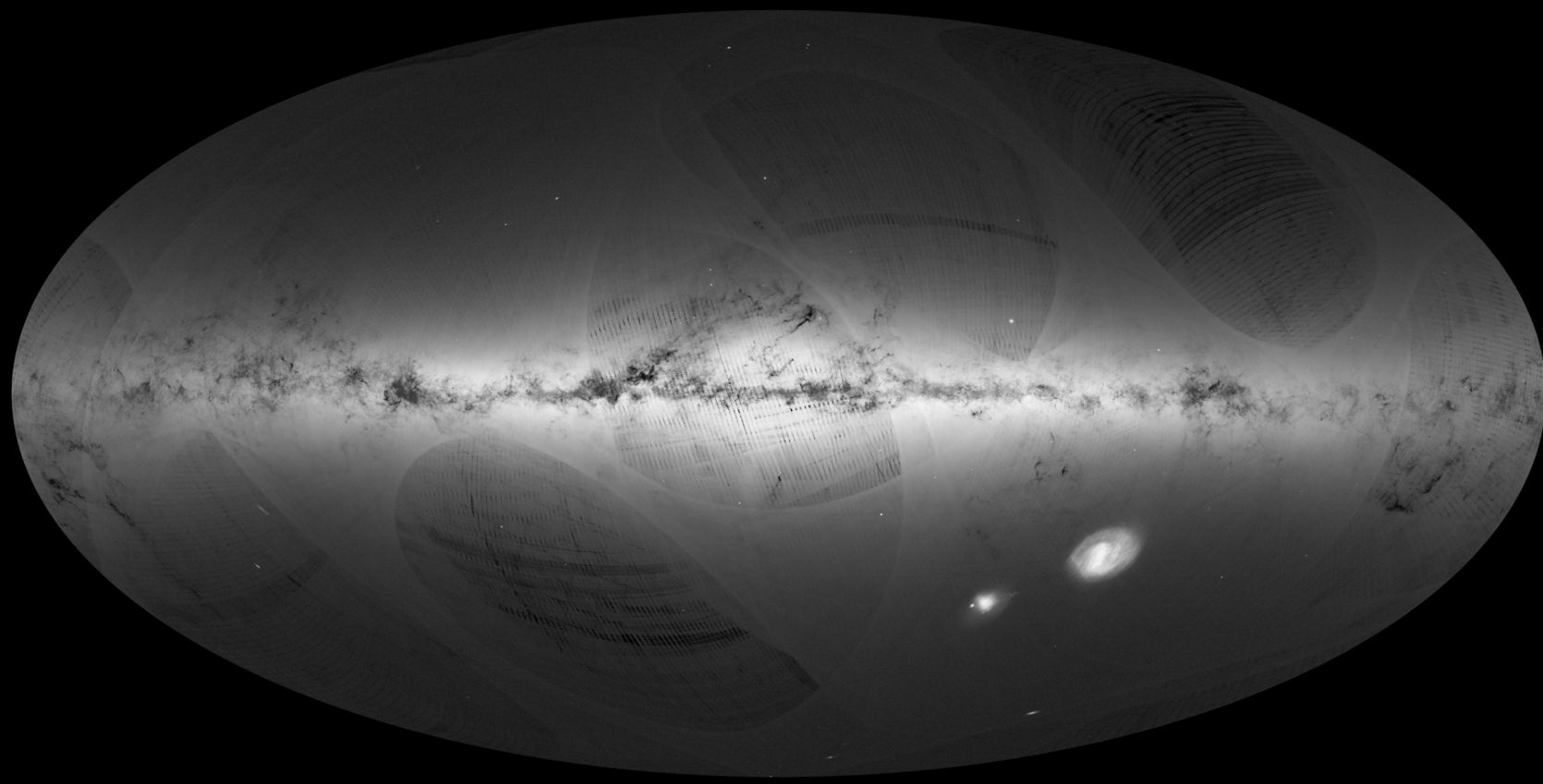




12 Dec 2016

A first data release

- Gaia mission overview
- Gaia DR1 content
- Validations and limitations



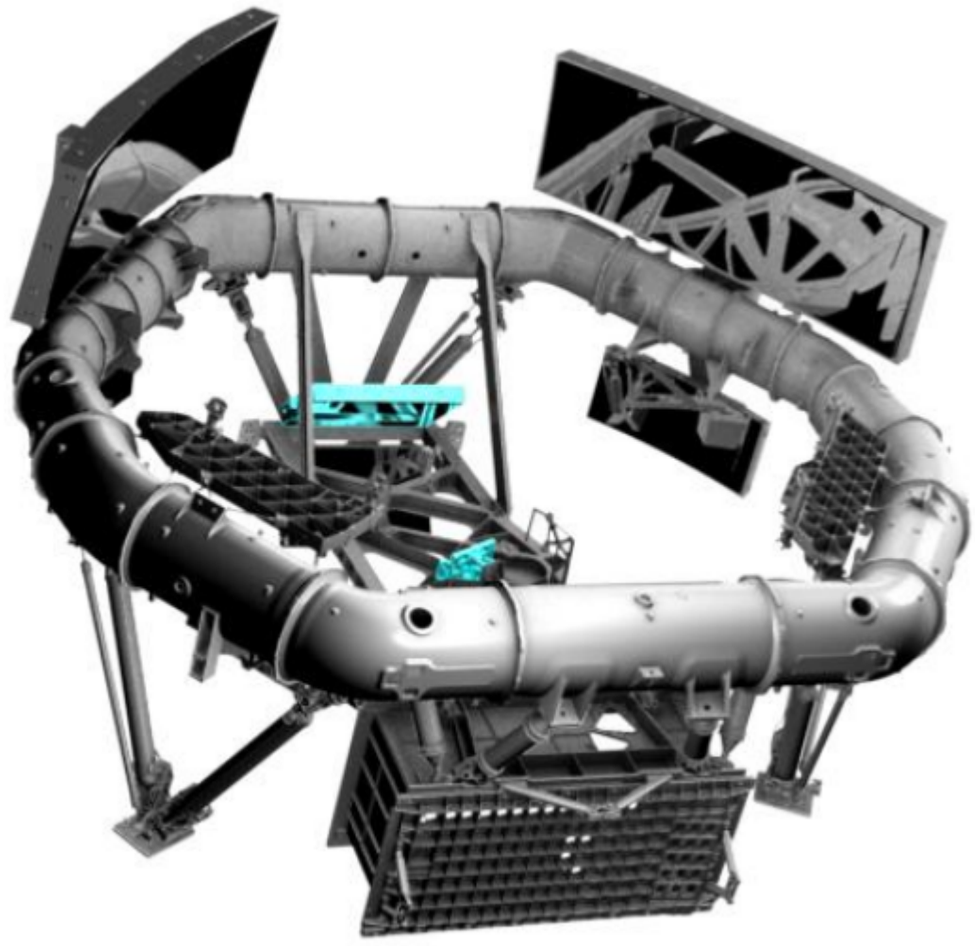
The Gaia mission

ESA cornestone mission

5 years of mission

3 instruments

- Astrometry
- Spectrophotometry
- Spectroscopy (RVS)

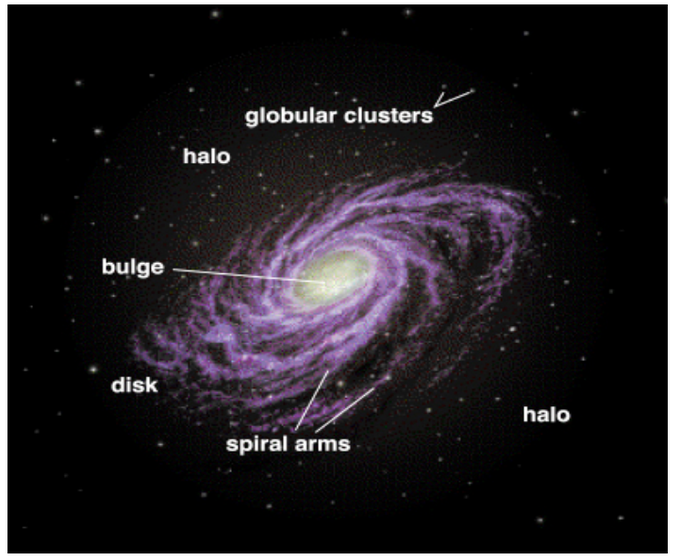


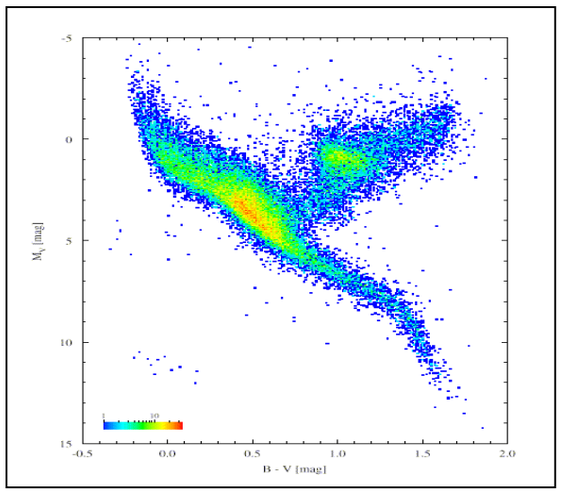
· > 1 billion stars 3 < **G < 20.7**

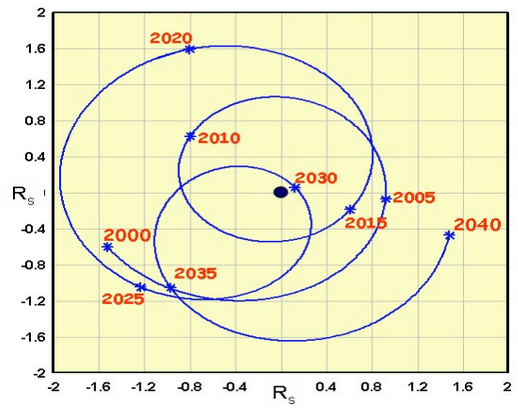
· ~ 70 observations per source

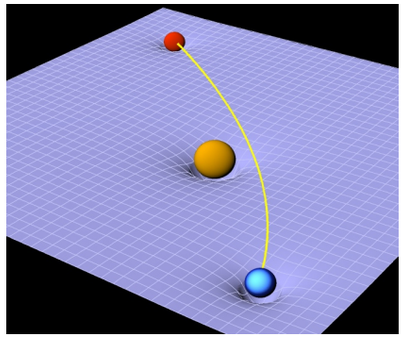
Gaia scientific objectives

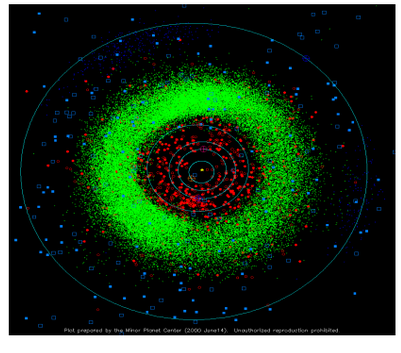
- The Galaxy: structure, formation, evolution
- Stellar physics
- Distance scale
- Local Group dynamics
- Solar system
- Interstellar medium
- Extra-solar planets
- Fundamental physics
- Serendipity !











Parallax horizon for G0V stars

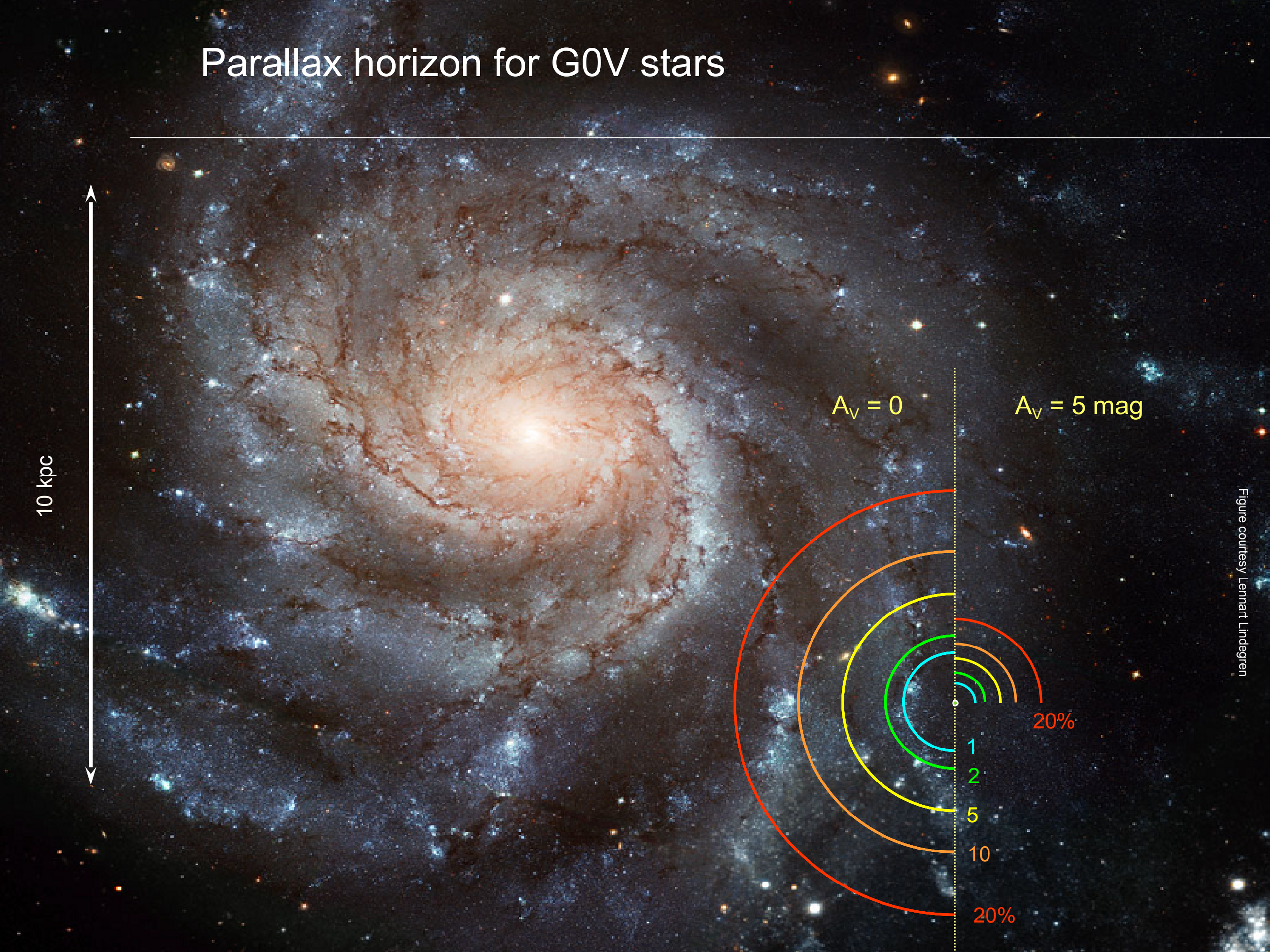


Figure courtesy Lennart Lindegren

Parallax horizon much more distant for cepheids

10 kpc

10%

5%

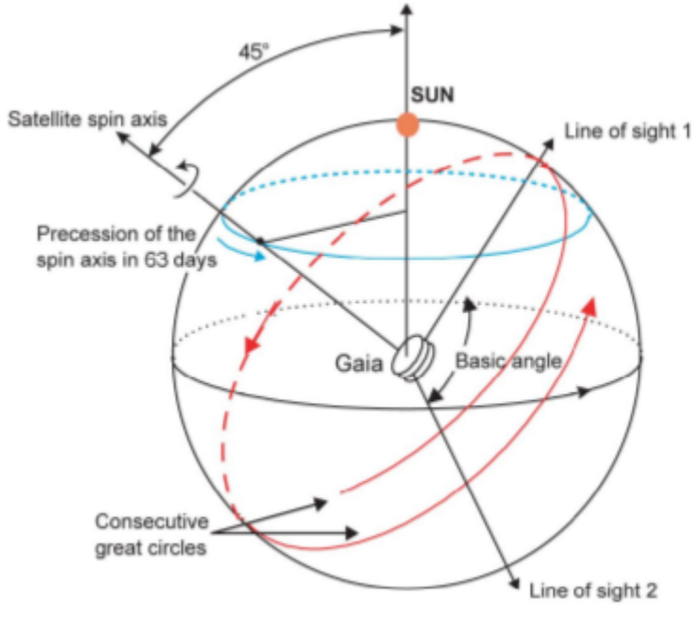
1%

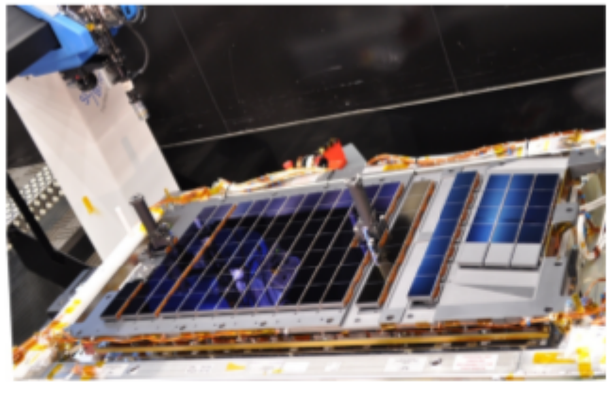
2%

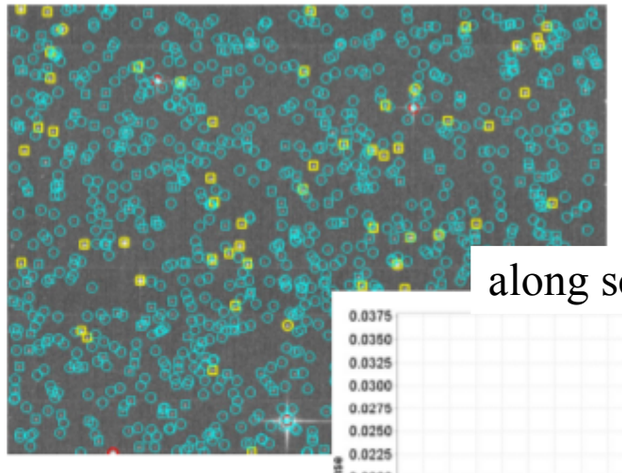
Jos de Bruijne

Figure courtesy Lennart Lindegren

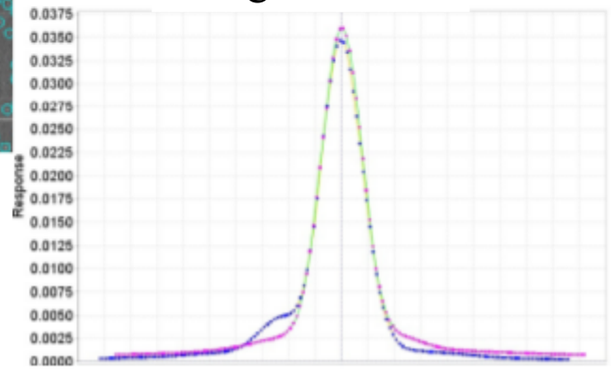
Gaia instruments and measurements

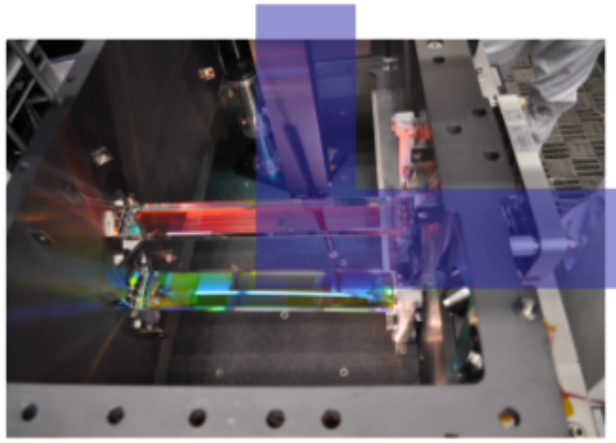




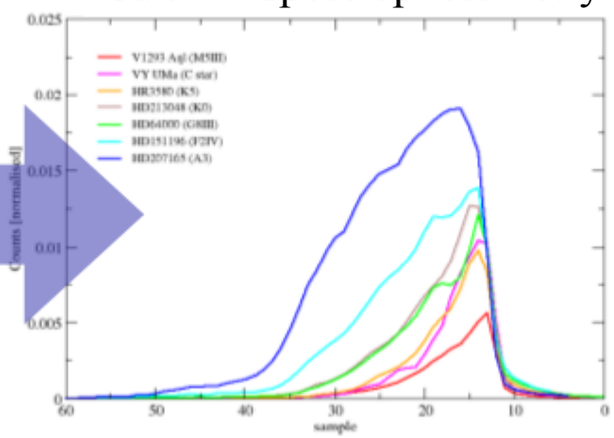


along scan LSF

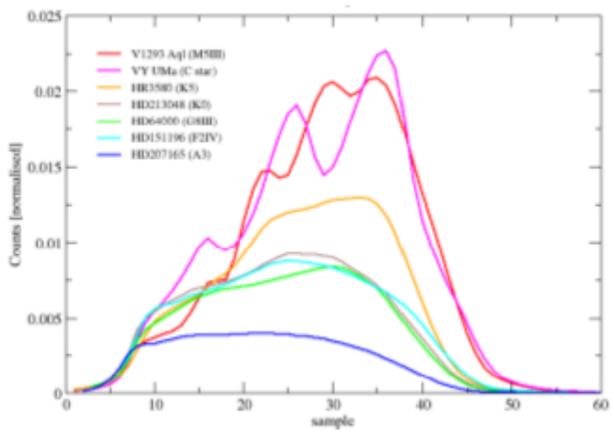


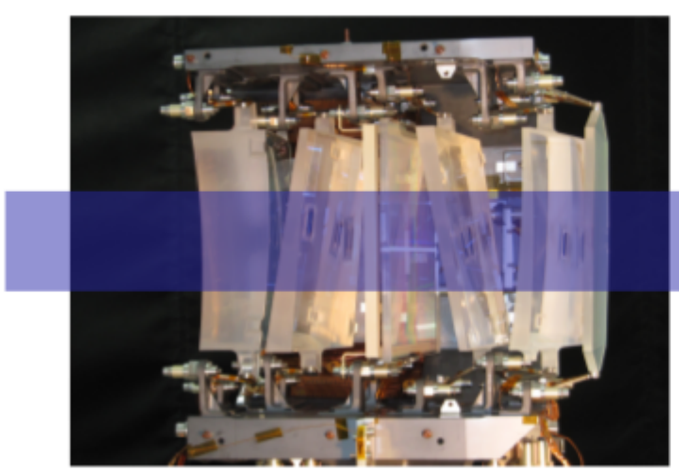


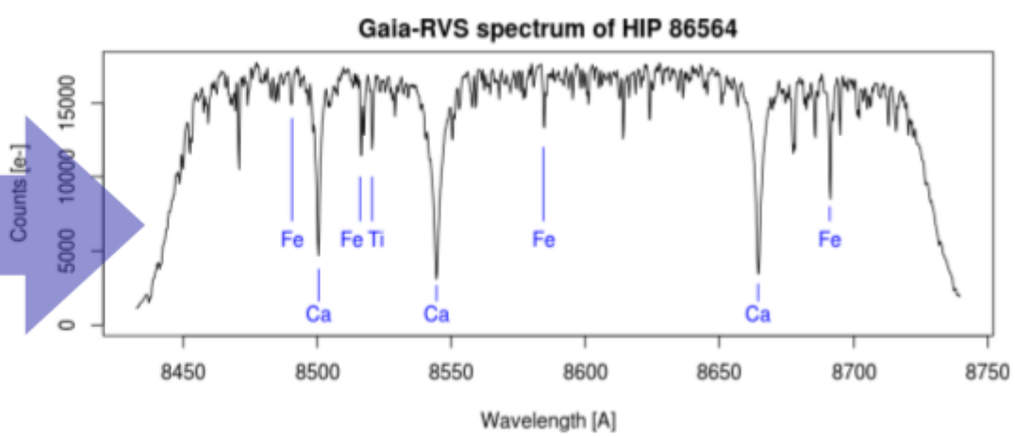
Gaia BP spectrophotometry



Gaia RP spectrophotometry



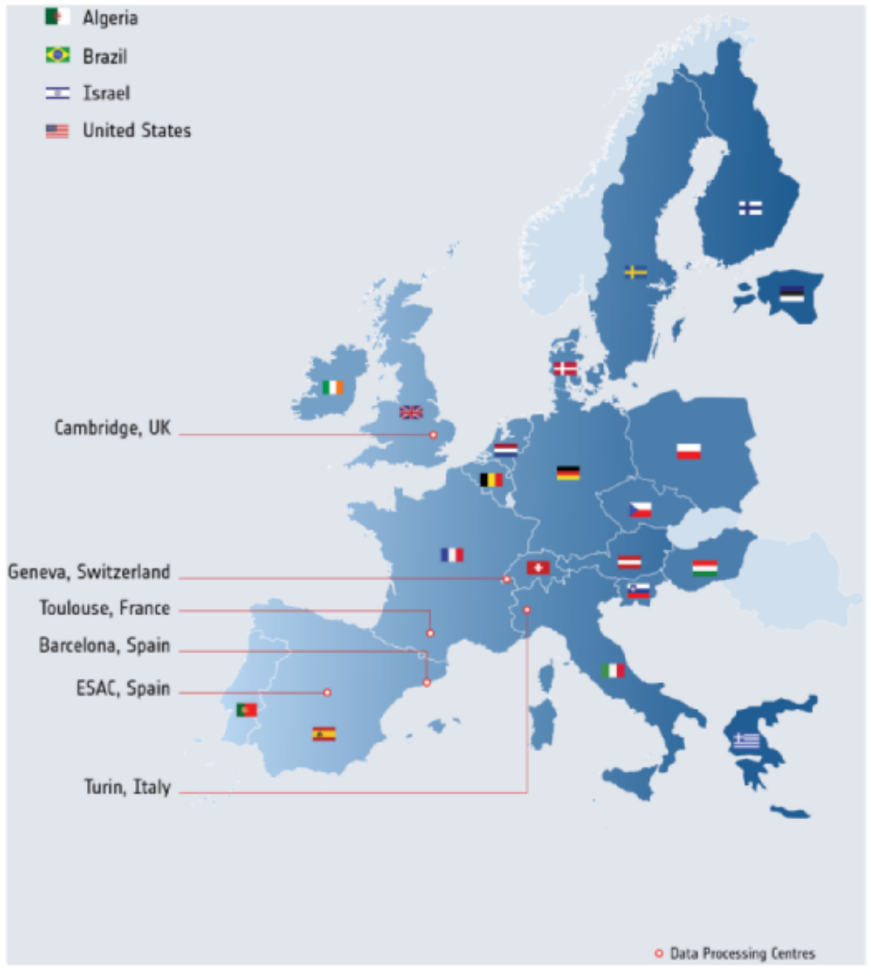




Figures:
ESA/Gaia/DPAC/Airbus DS

Teamwork to deliver the promise of Gaia

- 10+ years of effort
- 450 scientists and engineers
- 160 institutes
- 24 countries and ESA
- Six data processing centres



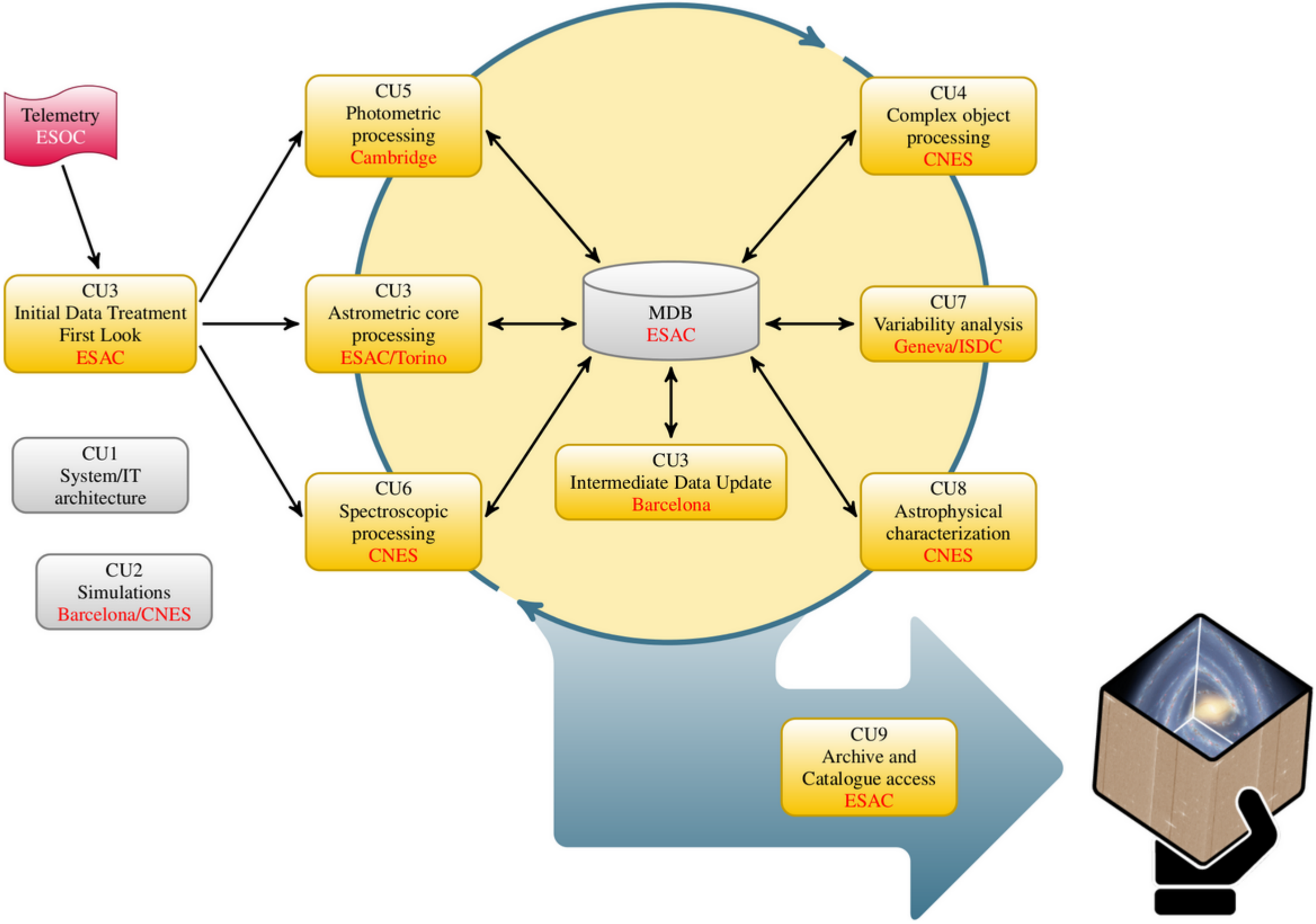
gaia

0 1 0 0 0 0 0 1 1 0 0 1 0 0 1 1 0 0 1 1 0 1 1 0 1 1 0 0 1 0 1 0

Gaia DPAC Data Processing & Analysis Consortium

α δ ϖ $\mu_{\alpha*}$ μ_δ G ...

Gaia data processing



The Gaia schedule

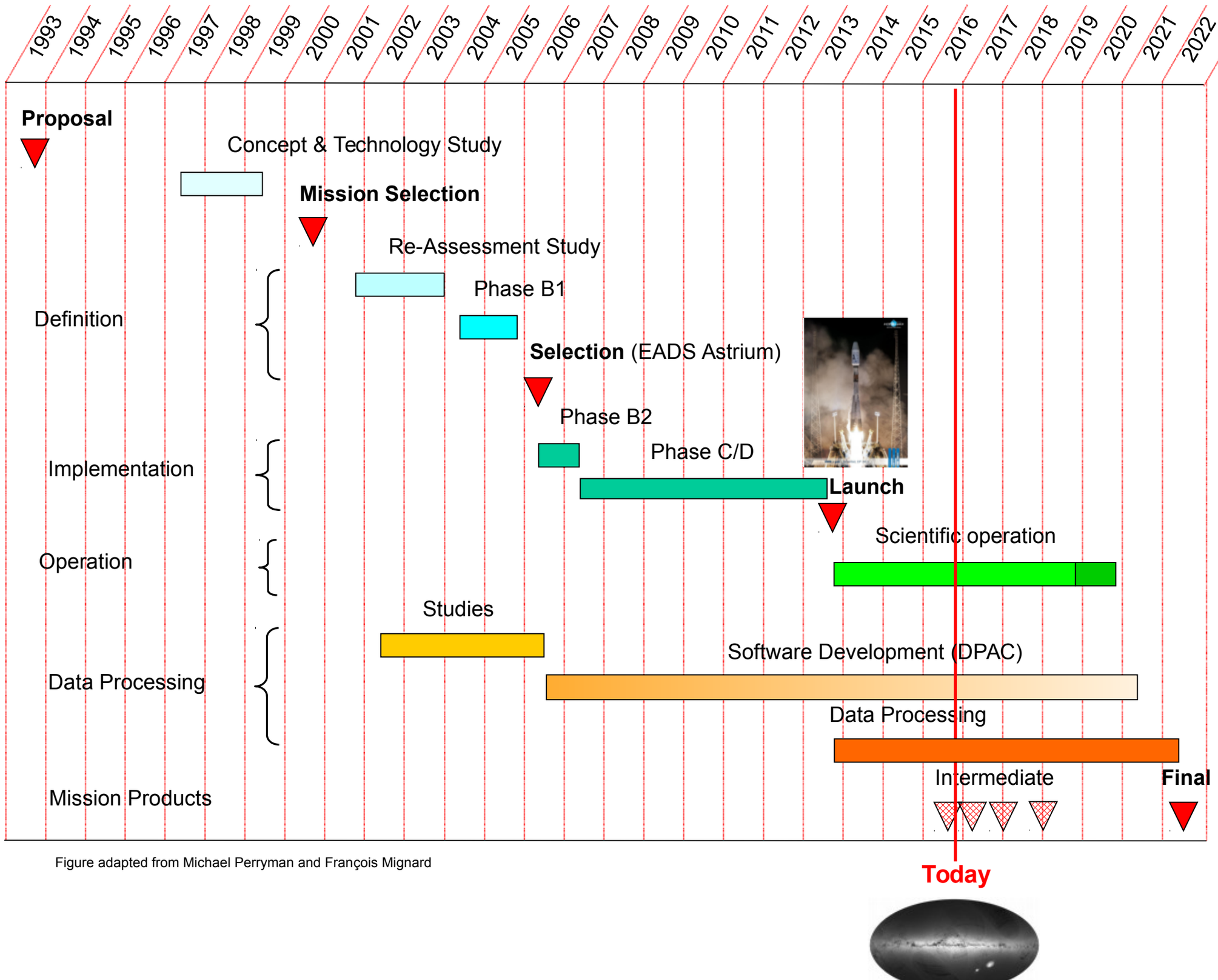
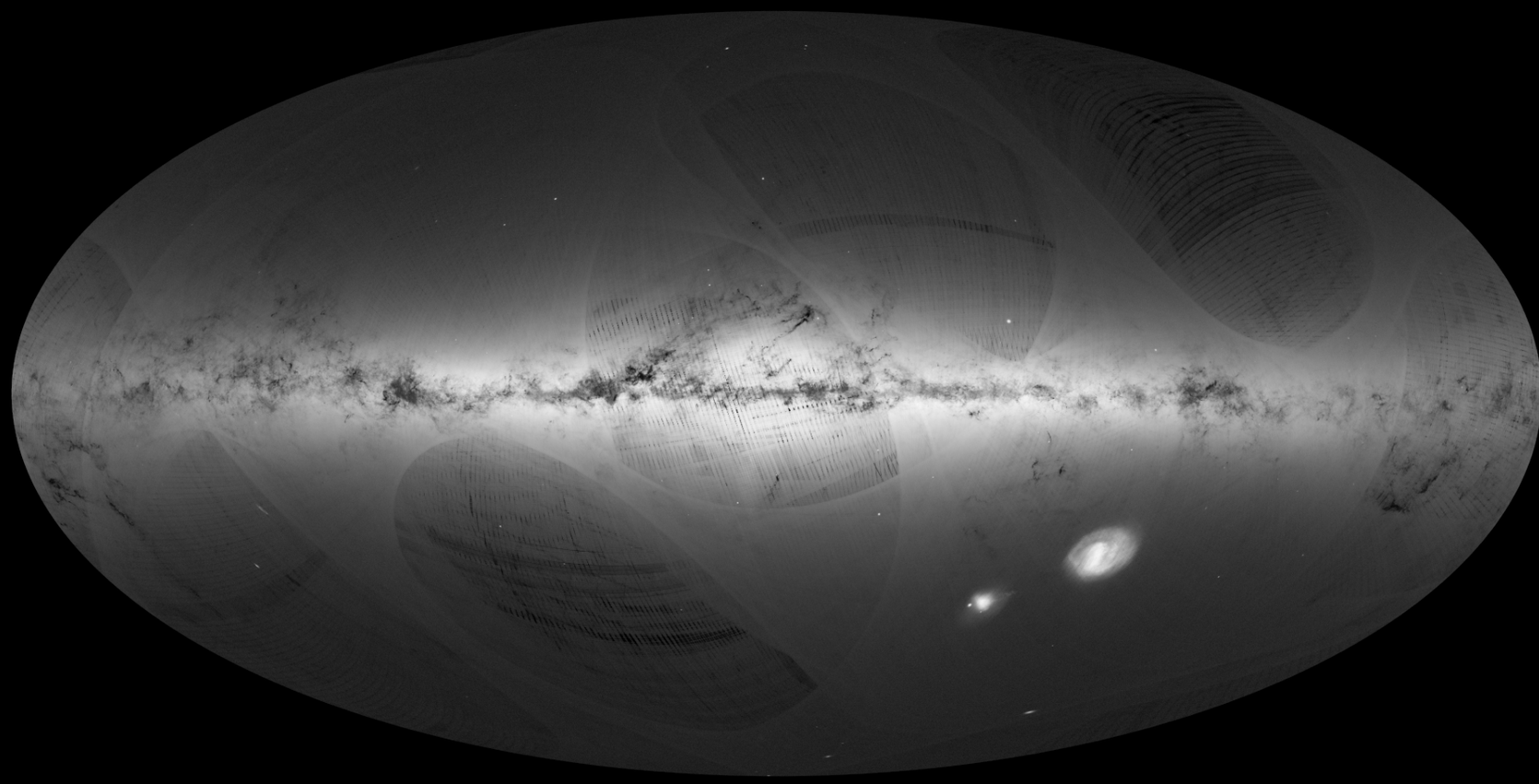


Figure adapted from Michael Perryman and François Mignard

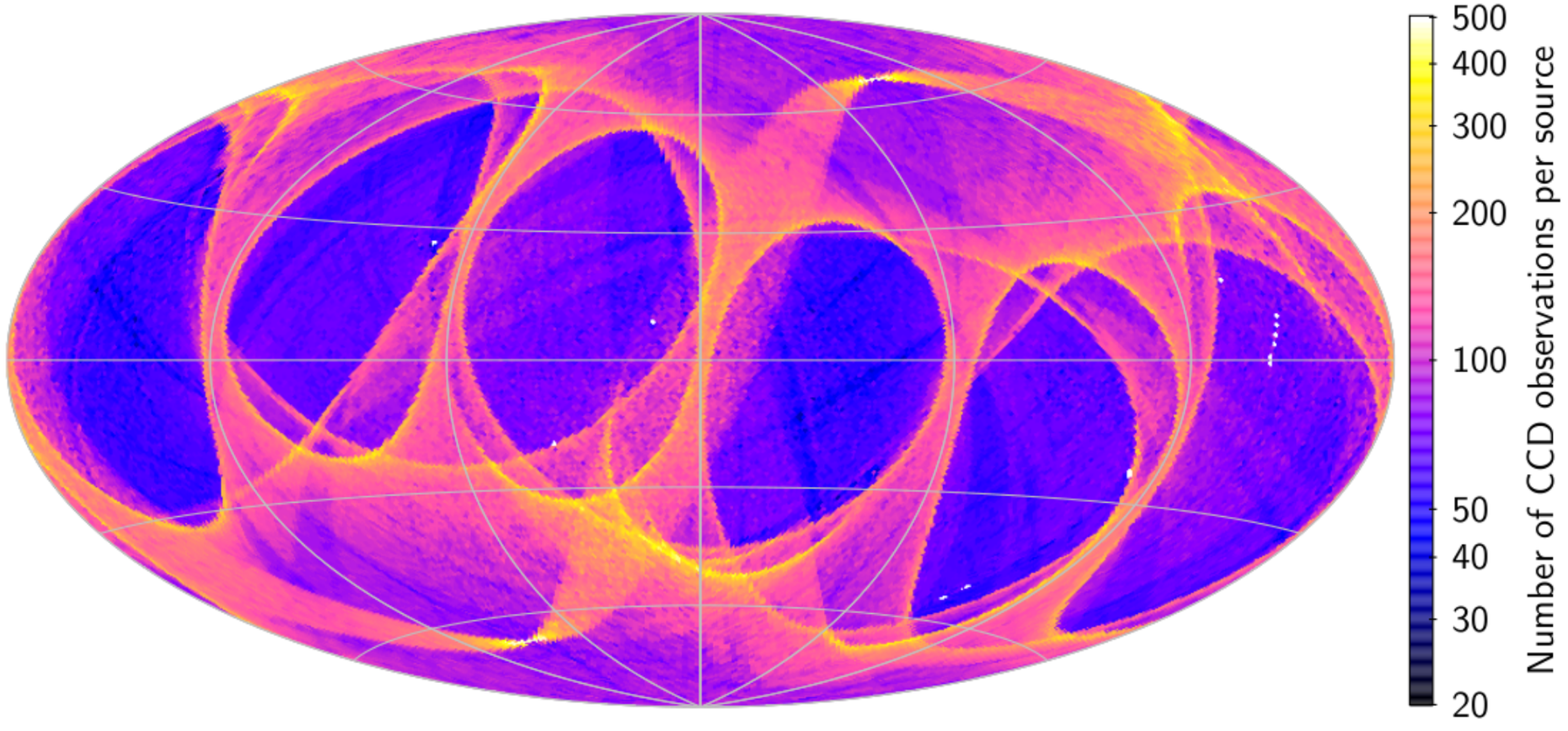
A first data release

- Gaia mission overview
- Gaia DR1 content
  - astrometry
  - photometry
- Validations and limitations



Gaia DR1 input data

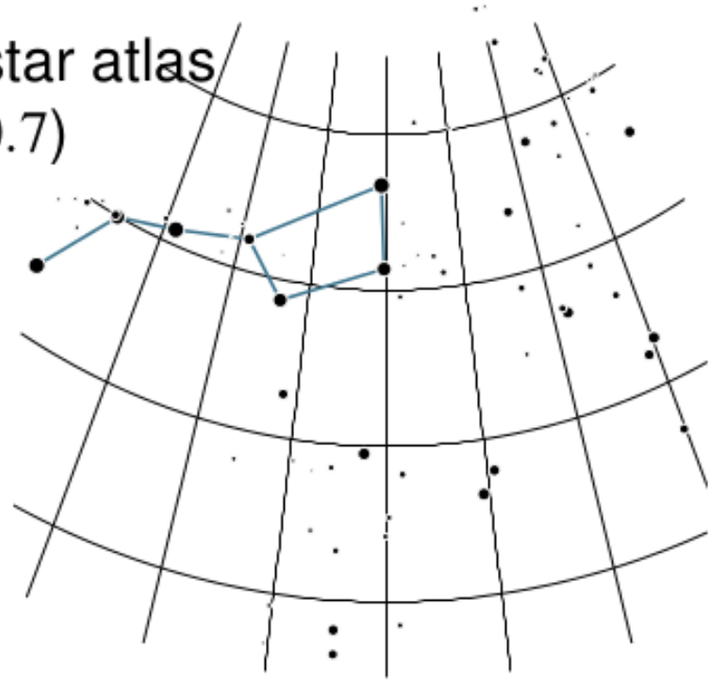
- 14 months of input data used
- ~ 2.3 10^{10} transits (1 month EPSL than Nominal Scanning Law)
- all sources treated as single



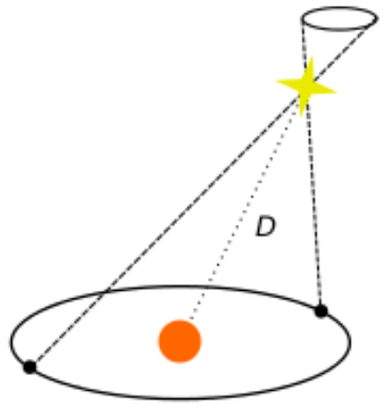
DPAC/CU3/Lindegren et al., 2016, A&A

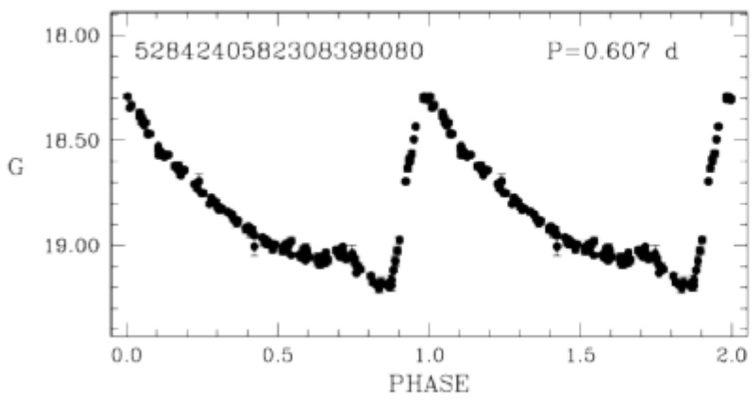
What's in the Gaia DR1 delivery

Billion star atlas
($G \lesssim 20.7$)



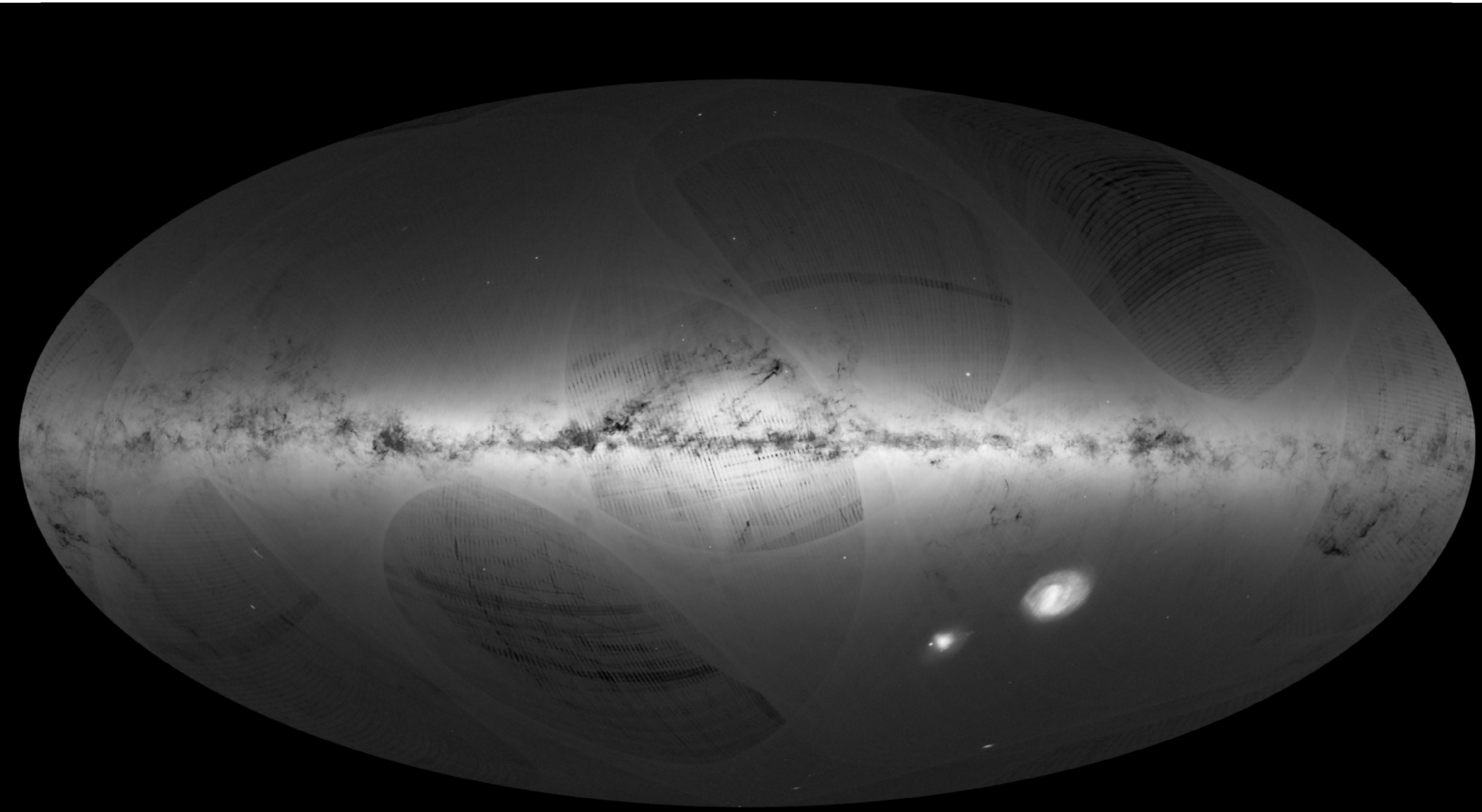
Tycho-Gaia
Astrometric Solution
($\sim$ 2 million, $G \lesssim 12$)





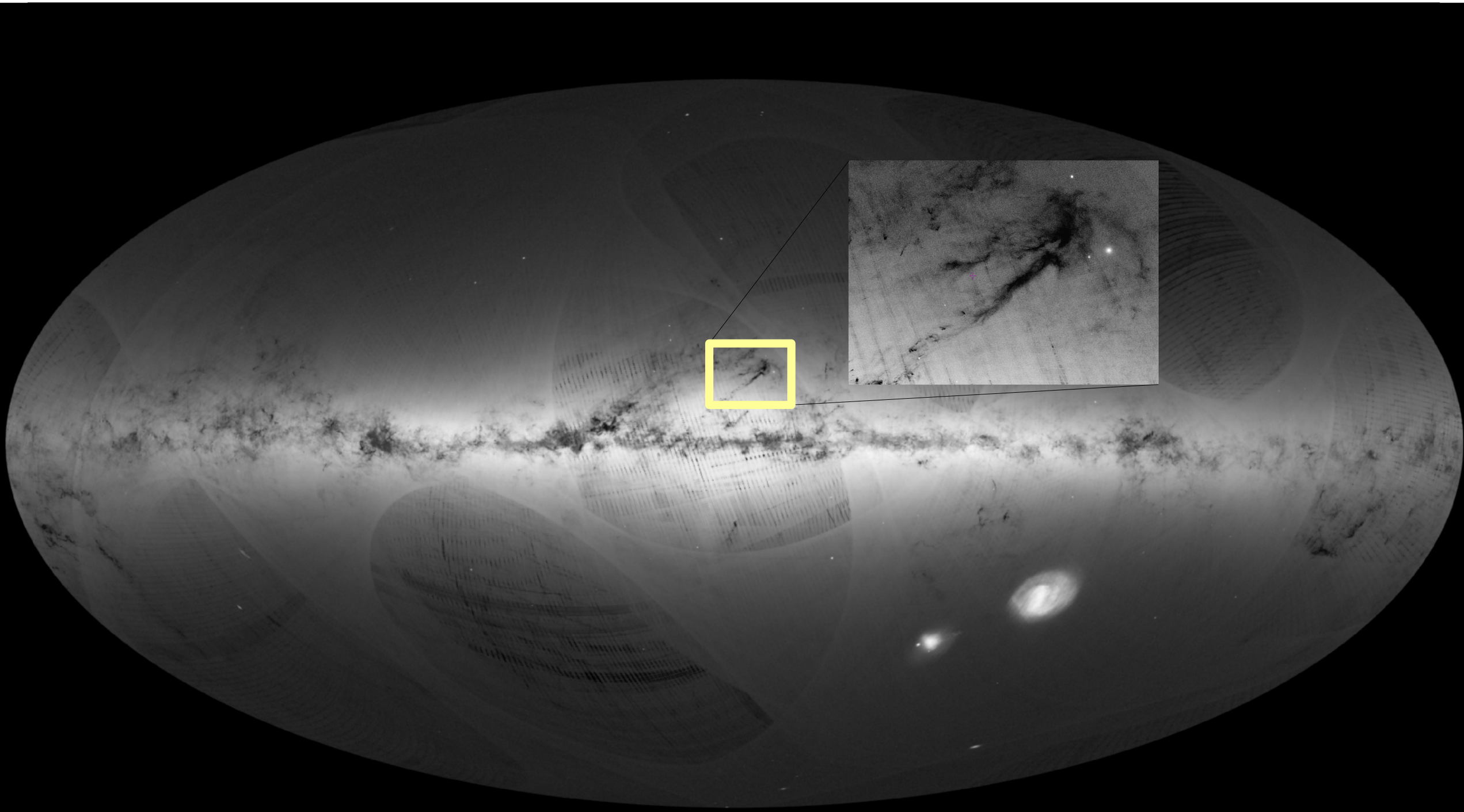
Variable stars near
south ecliptic pole
($\sim$ 600 Cepheids,
$\sim$ 2600 RR Lyrae)

Gaia DR1 skymap



ESA/Gaia/DPAC/André Moitinho & Márcia Barros (CENTRA - University of Lisbon)

Gaia DR1 skymap



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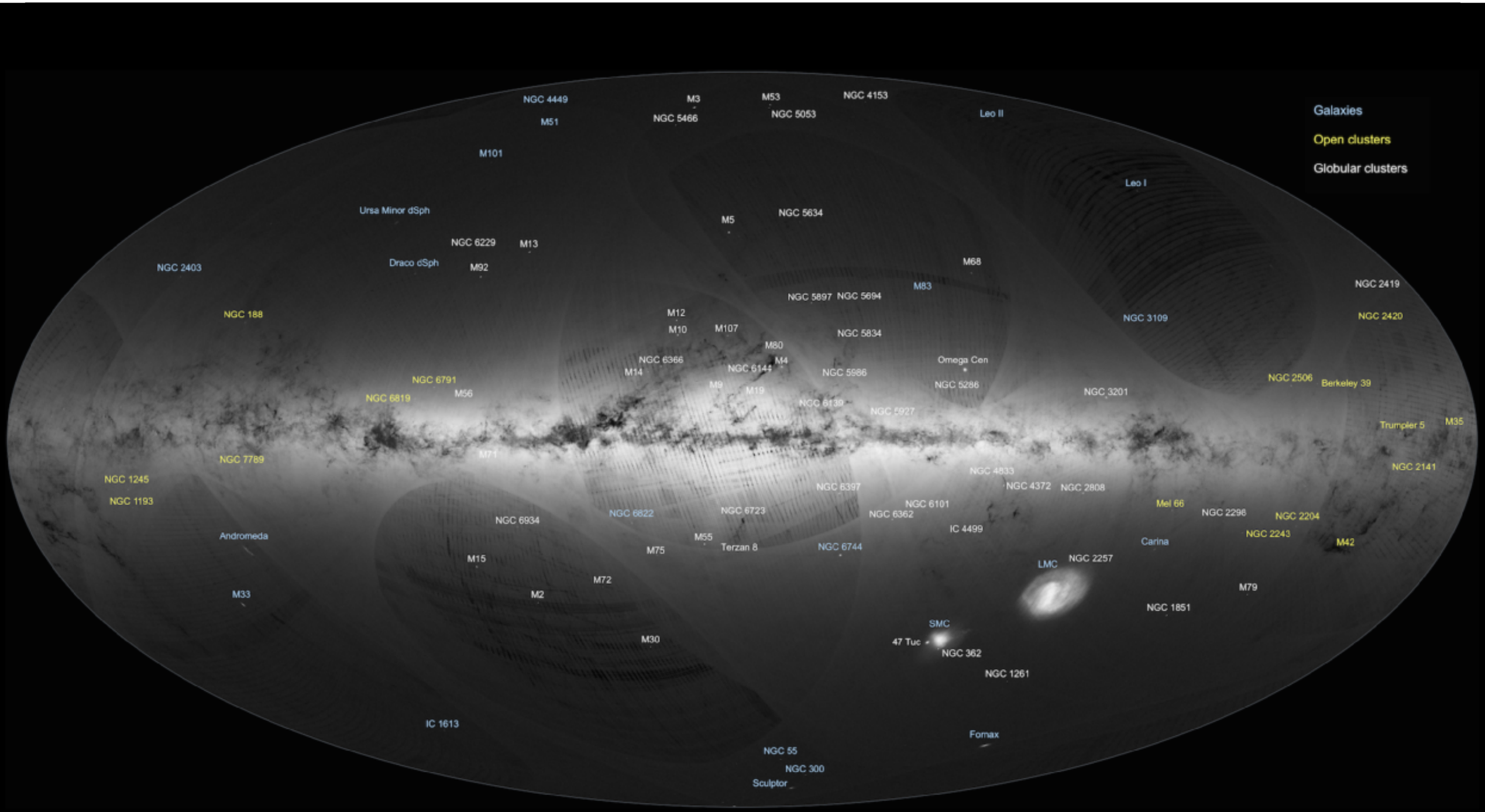
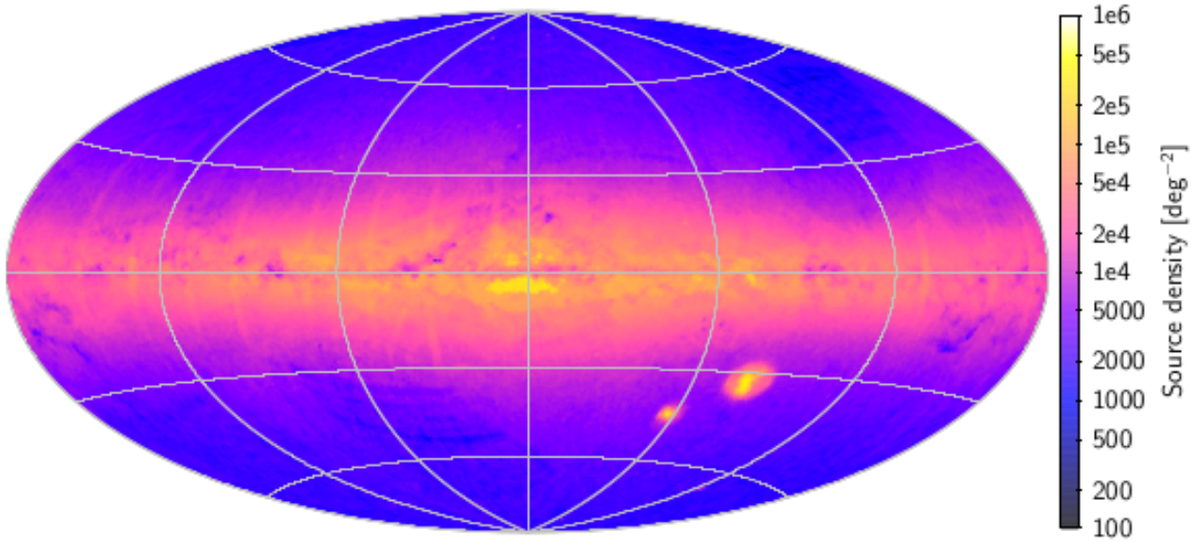
Gaia DR1 skymap



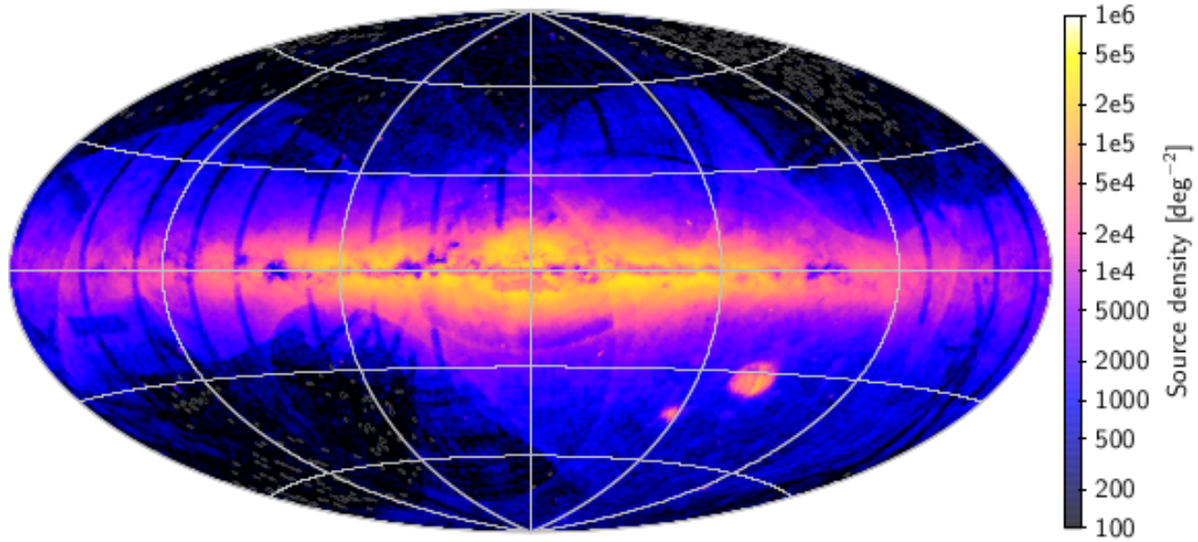
ESA/Gaia/DPAC/André Moitinho & Márcia Barros (CENTRA - University of Lisbon) Annotations: Francois Mignard (OCA Nice)

Gaia DR1 astrometry

685 million sources matched to IGSL



456 million new sources in Gaia DR1



DPAC/CU3/Lindegren et al., 2016, A&A

- (α, δ) for ~ 1.1 billion sources to $G = 20.7$
- Epoch J2015.0, alignment to ICRF < 0.1 mas, rotation < 0.03 mas yr^{-1}
- Typical position uncertainty ~ 10 mas
- Positions of 2191 ICRF sources from special astrometric solution (Mignard et al., 2016, A&A)
  - 90% with $\sigma_{\rm pos} < 3.35$ mas
  - no systematic differences with radio positions of more than few tenths of mas

TGAS

Tycho-Gaia Astrometric Solution (Michalik et al., 2015, A&A)

- Use Hipparcos or Tycho-2 position as prior to disentangle parallax and proper motion
  - 2 million stars in common with these catalogues
- 5-parameter astrometry from $\sim$ 1 year of Gaia data
- *No Hipparcos parallaxes used*

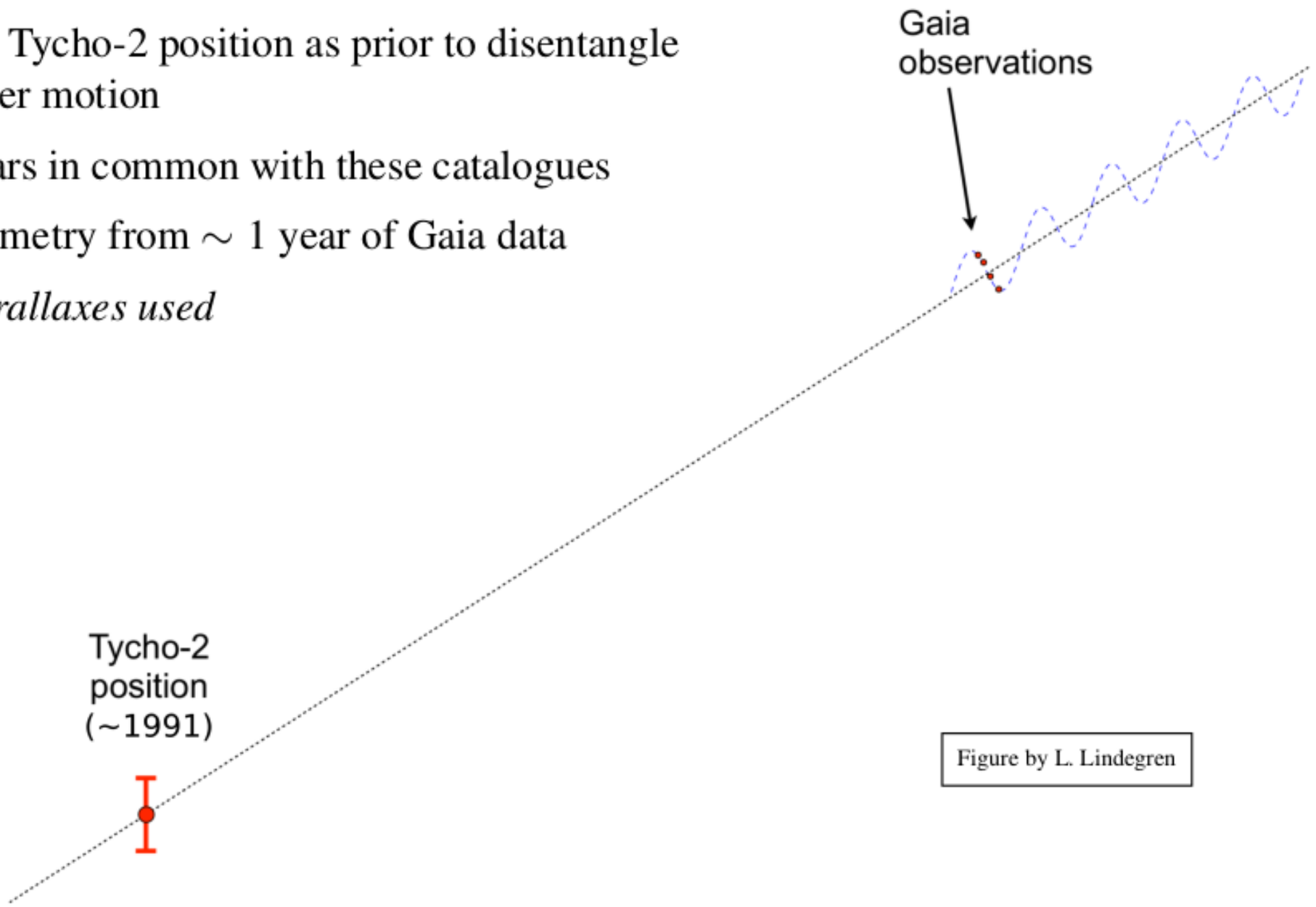
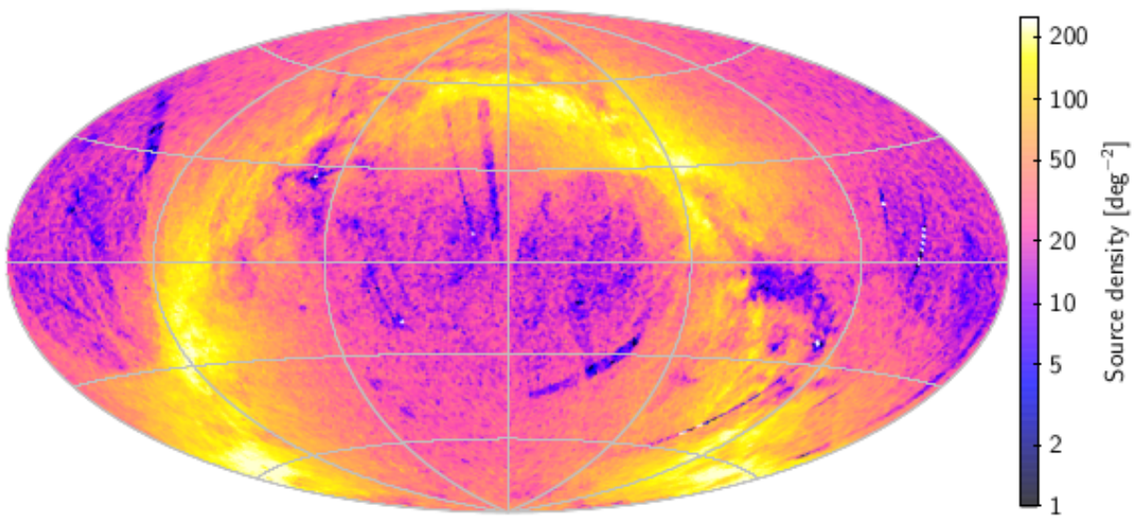


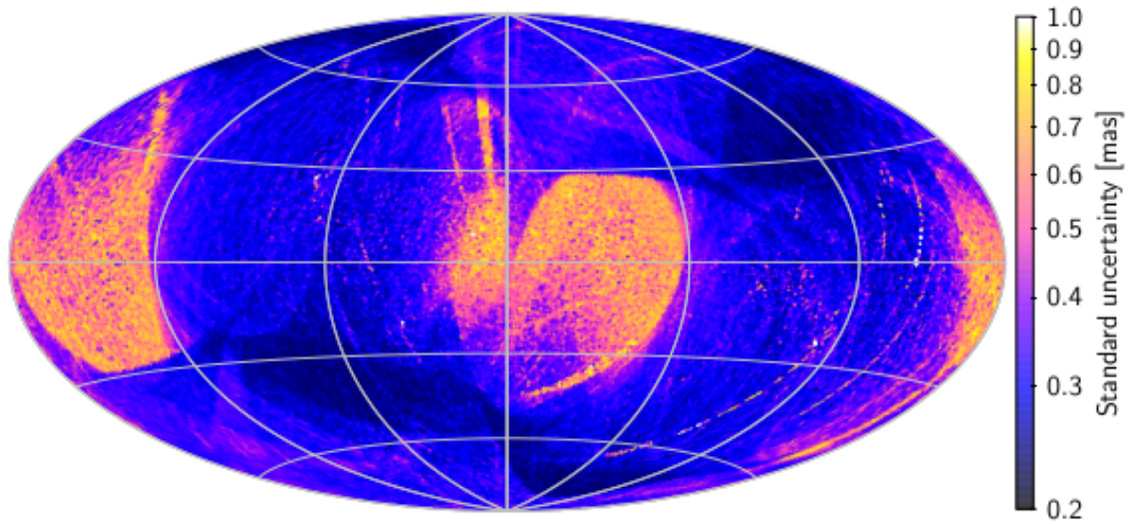
Figure by L. Lindegren

TGAS

TGAS source density



TGAS median parallax uncertainty

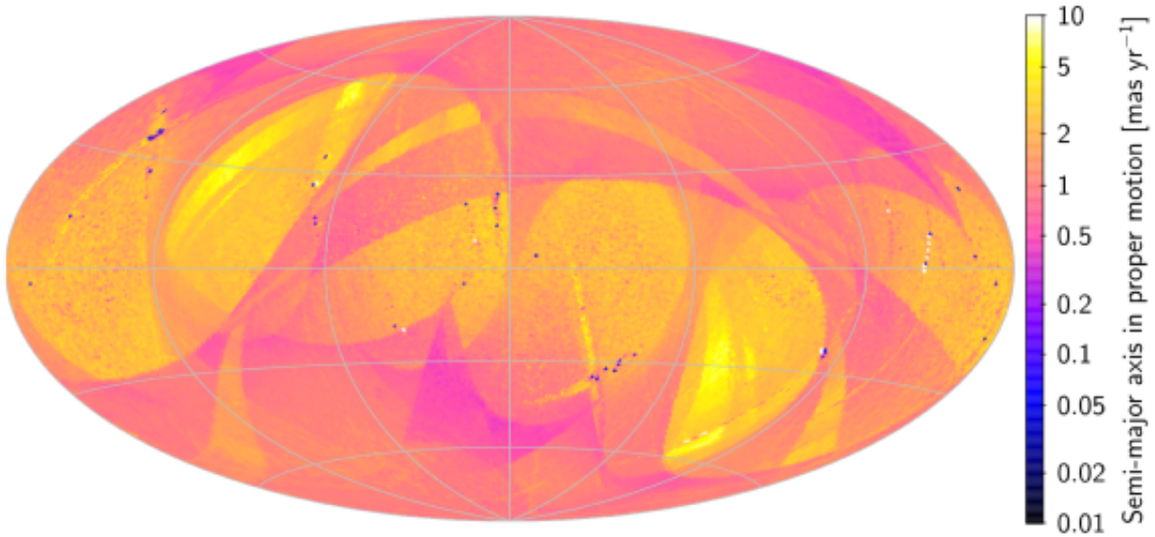


DPAC/CU3/Lindegren et al., 2016, A&A

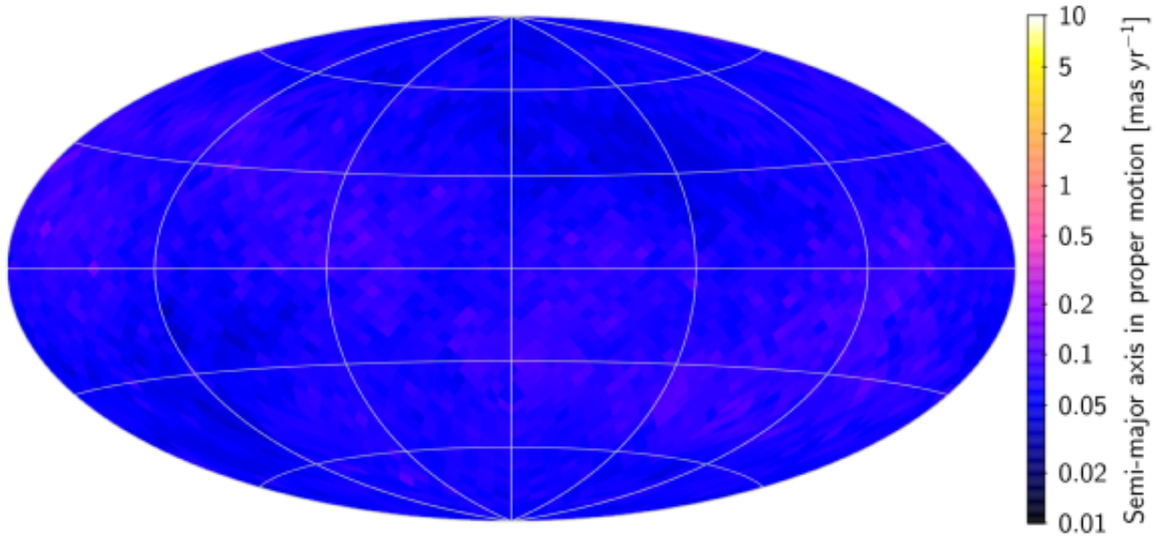
- Parallaxes and proper motions for ~ **2 million** sources to G ~ 11.5
- Realistic errors derived from Gaia – Hipparcos comparison
- Median **parallax** uncertainty ~ 0.3 mas; global zeropoint below 0.1 mas; systematics at 0.3 mas level

TGAS

TGAS median proper motion uncertainty



Hipparcos subset

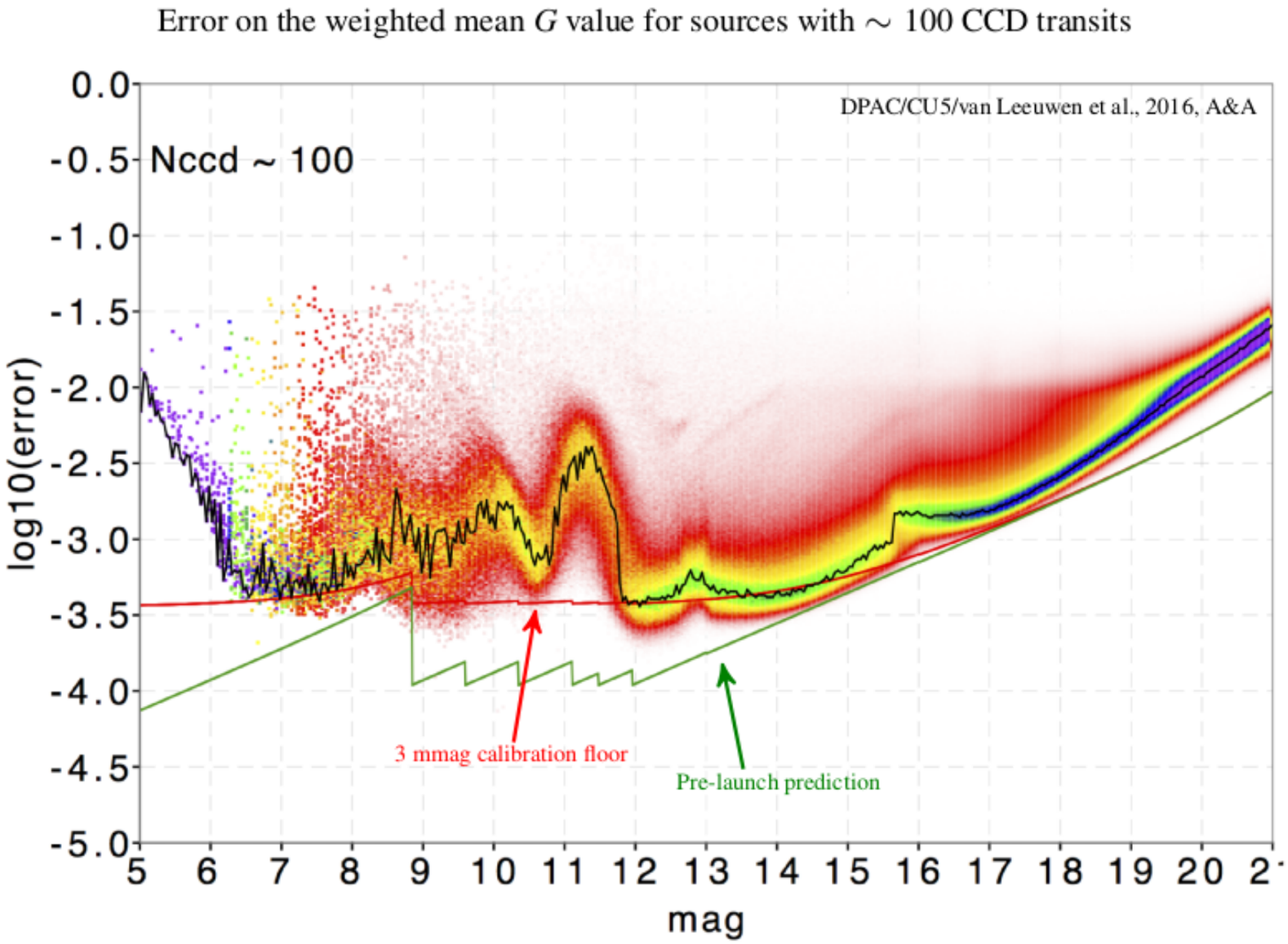


DPAC/CU3/Lindegren et al., 2016, A&A

- Median **proper motion** uncertainty ~ 1.3 mas yr^{-1}

  Hipparcos subset: ~ 0.07 mas yr^{-1}

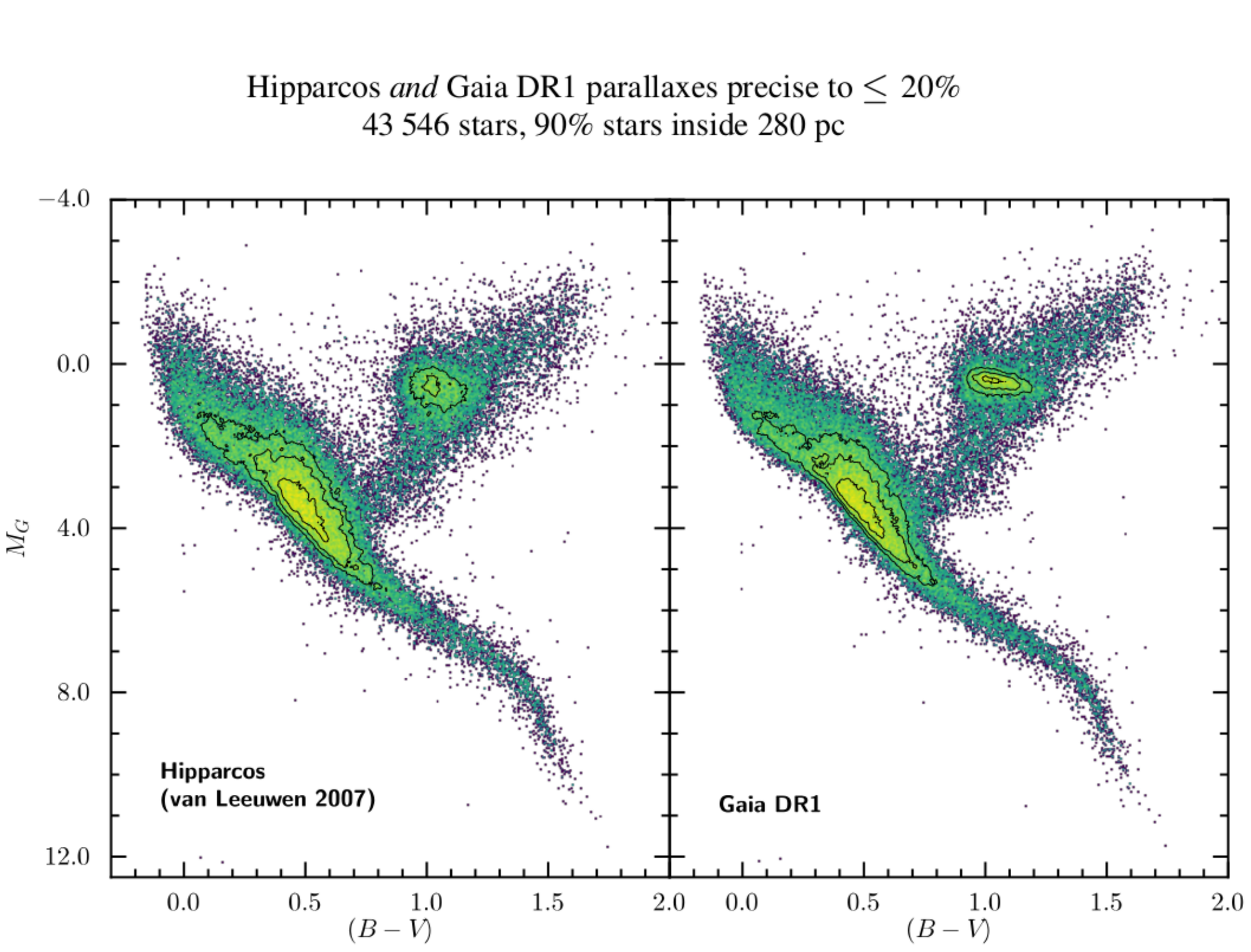
Gaia DR1 Photometry



- Mean *G*-band fluxes and errors for all Gaia DR1 sources
  - *G* magnitudes in VEGAMAG, zeropoints for AB
  - No pass-band calibrations, transformations to other systems to be provided

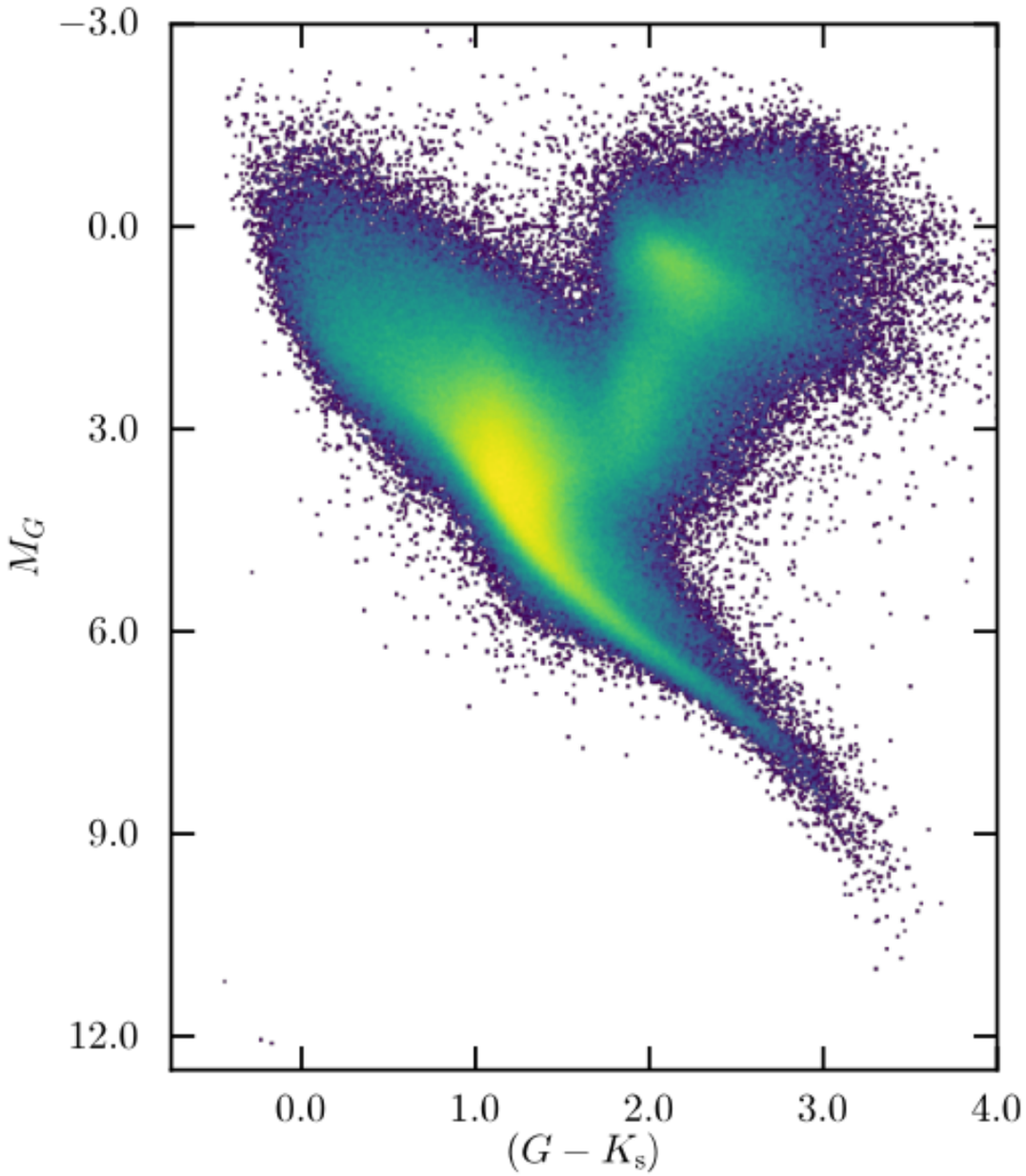
- CCD-transit *G*-band calibration systematics at the ~ 3 mmag level
- Bright end features related to on-board instrument configuration changes
  - will be calibrated out in future releases

TGAS HR diagram of the Hipparcos stars



Gaia Collaboration, Brown et al. 2016, A&A

TGAS full HR diagram

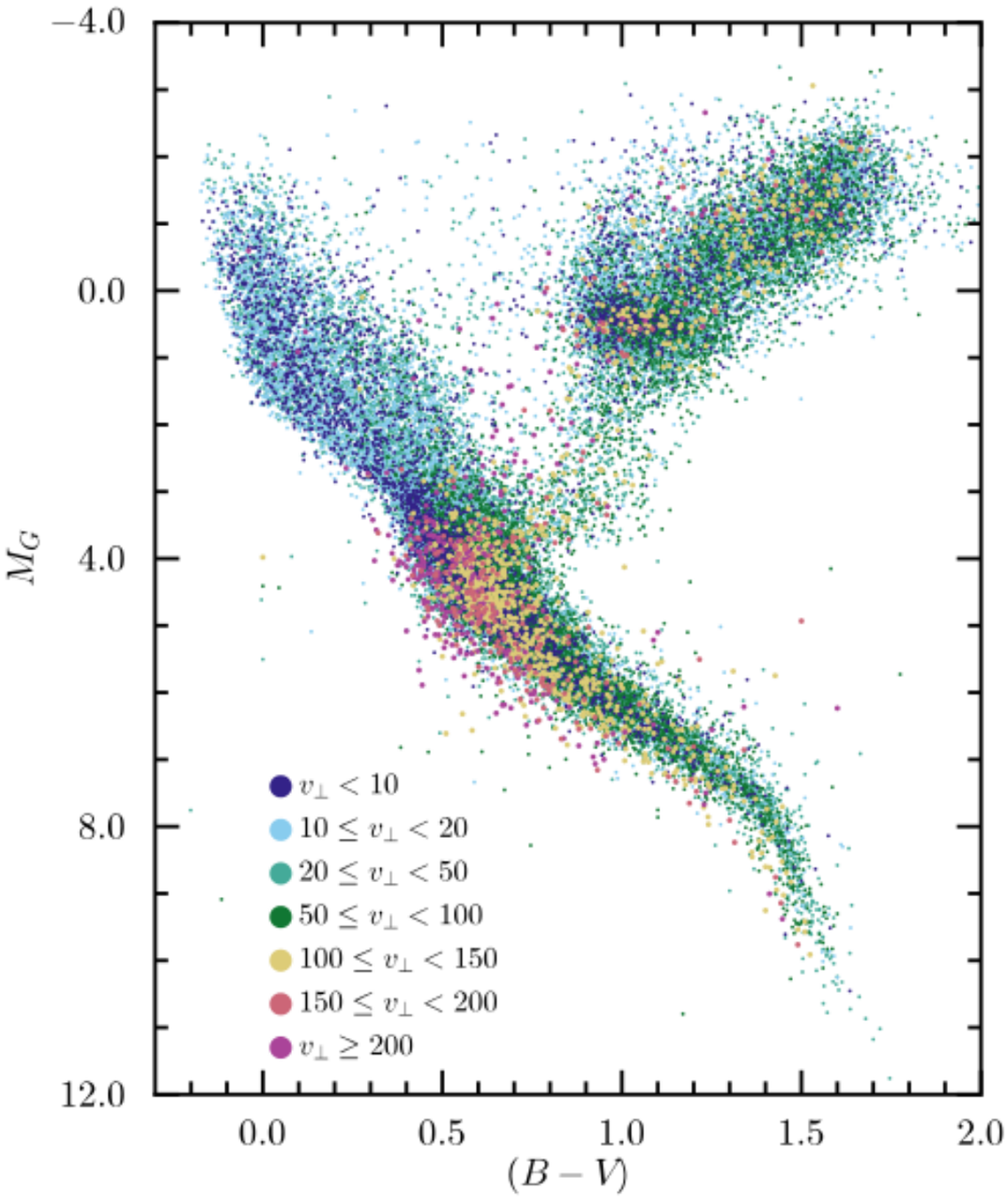


Full Gaia DR1 data set

- 1 million stars with parallaxes precise to $\leq 20\%$
- 90% inside 590 pc
- Future
  - $\sim$ 10 million parallaxes precise to 1%
  - $\sim$ 150 million precise to 10%
  - $\sim$ 280 million precise to 20%

Gaia Collaboration, 2016, A&A

HR diagram & tangential velocity

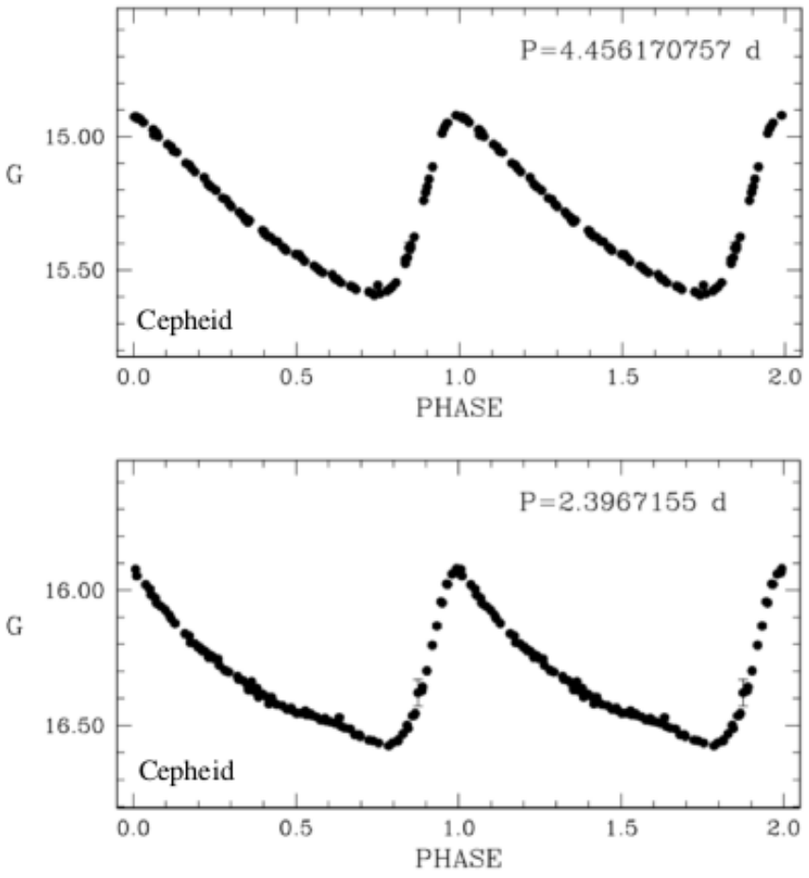


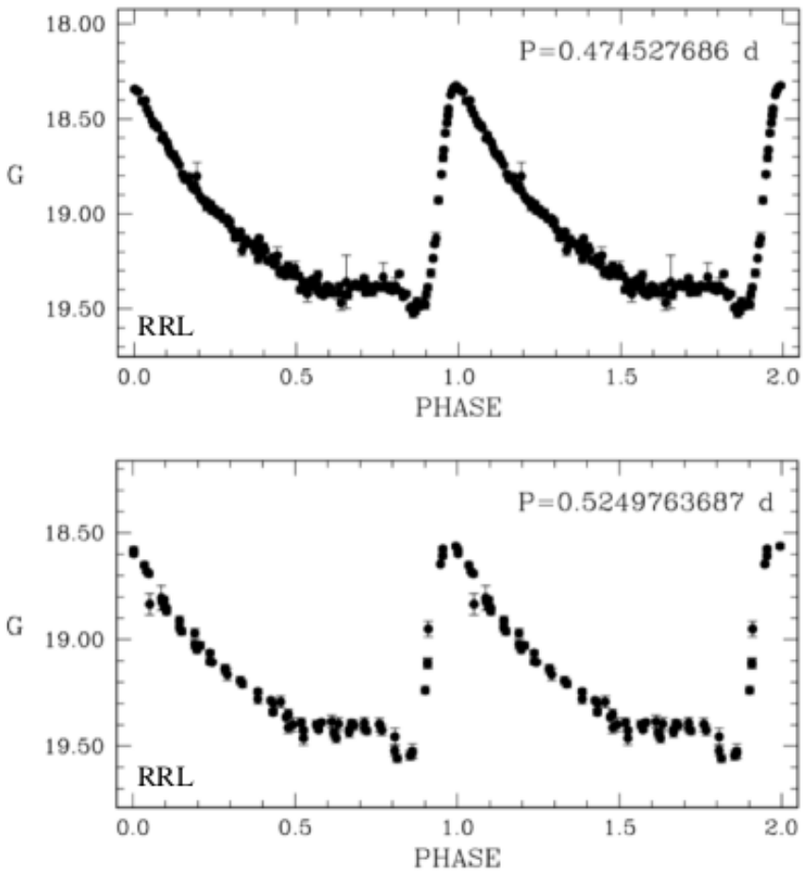
HR diagram colour coded by tangential velocity

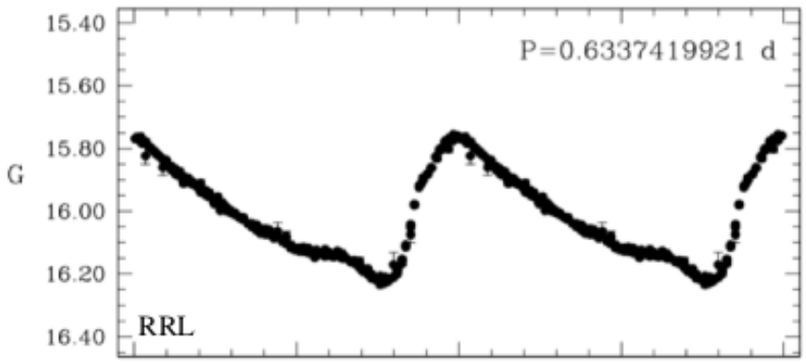
- 41 136 stars with $(B-V)$ photometry selected according to: $G \leq 7.5$ or $\mu \geq 200$ mas yr^{-1} or $\varpi \geq 10$ mas
- 90% inside 360 pc

Gaia Collaboration, 2016, A&A

Gaia DR1 Variable Stars





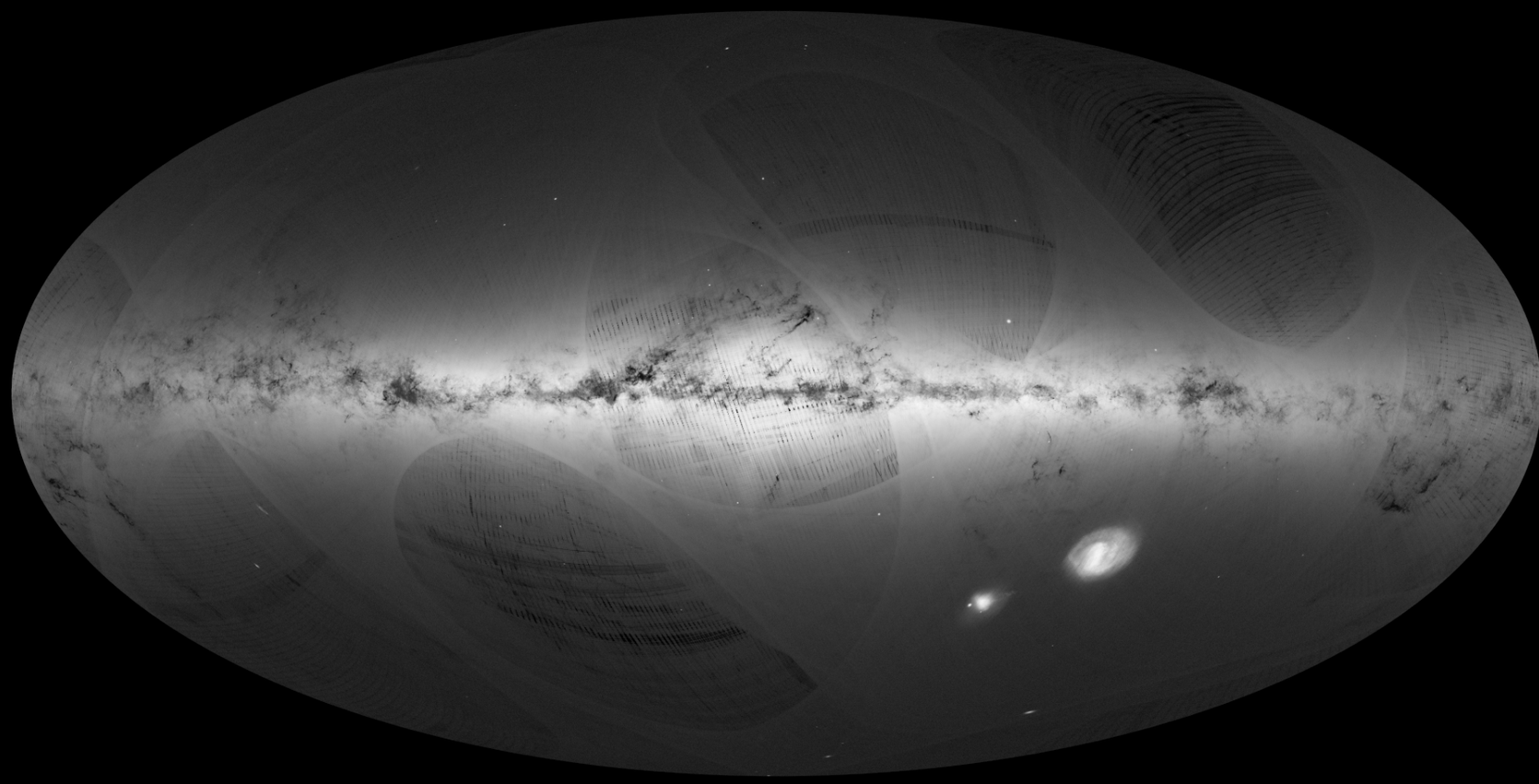


- *G*-band light curves for variables near South Ecliptic Pole
  - 599 Cepheids (43 newly discovered)
  - 2595 RR Lyrae (343 newly discovered)
- Classification information
- Statistical information on time series

DPAC/CU7/Clementini et al., 2016, A&A

A first data release

- Gaia mission overview
- Gaia DR1 content
- Validations and limitations
  - Completeness
  - Astrometry
  - Photometry



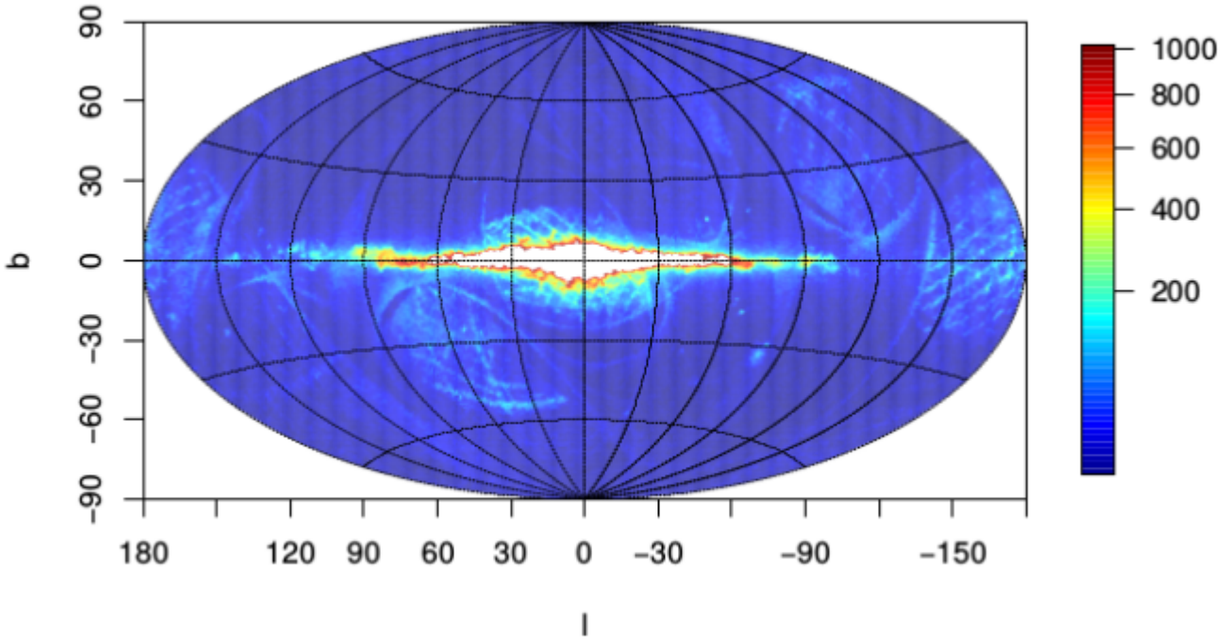
Compromise needed for an early first data release

- **Short observing period** (14 months)
  - → Bright stars position prior (Hipparcos/Tycho)
- **Calibration** models **not completed**
  - → Bright stars affected
- Attitude and other **un-modeled effects** (basic angle)
  - → Systematics
- **Sub-optimal cross-match**
- All sources **treated as single stars**

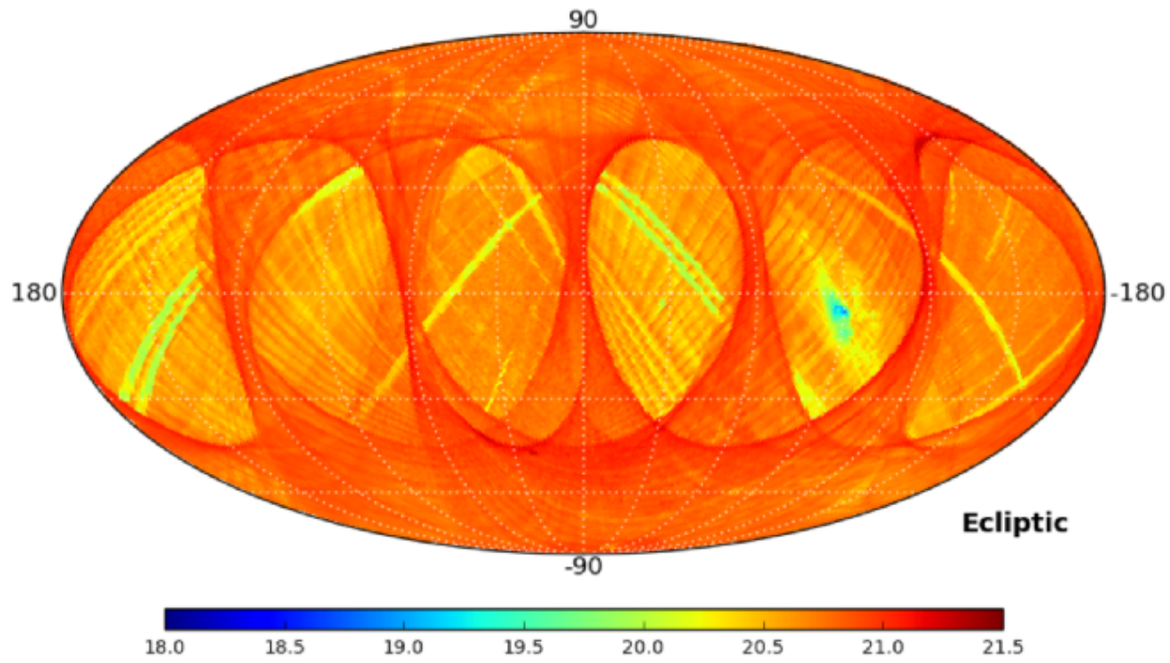
DR1 incompleteness

- Scanning law inhomogeneities

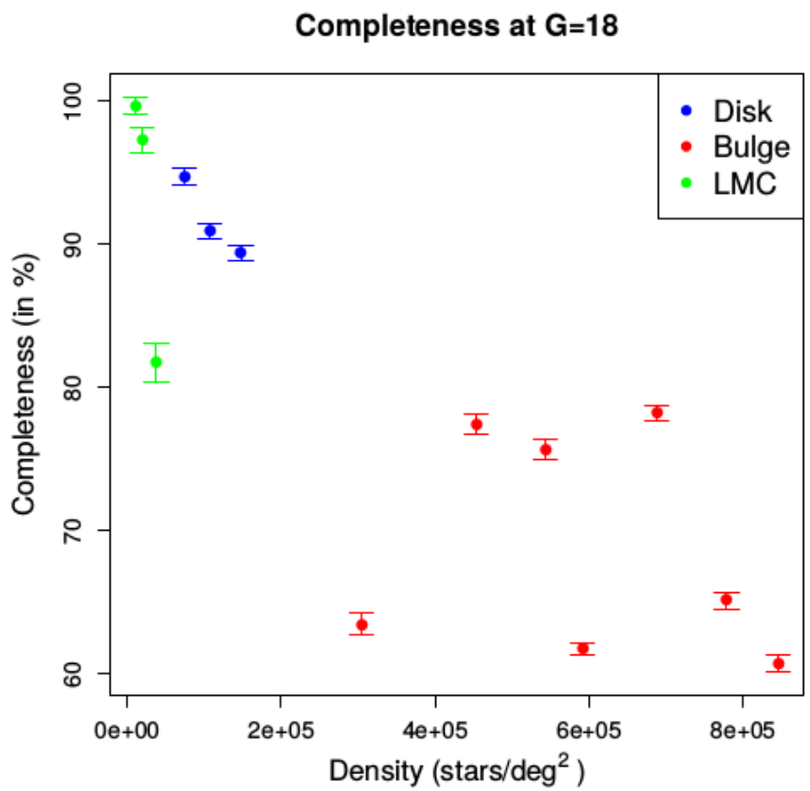
2MASS sources not found in DR1



99% percentile of the G mag distribution

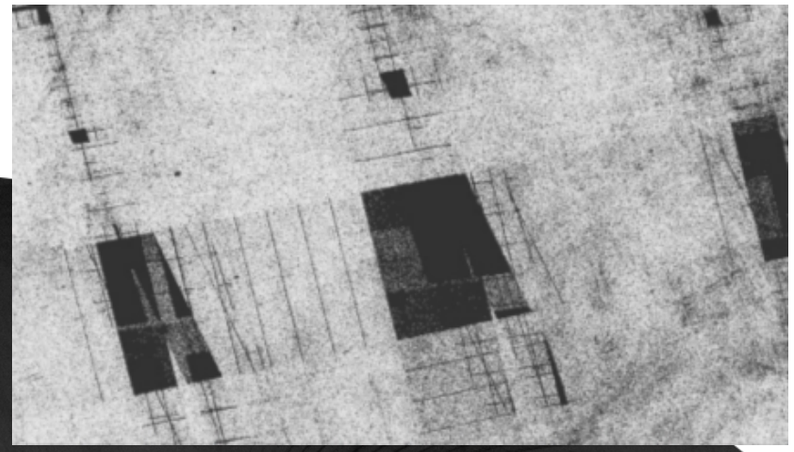


- Worst incompleteness in dense regions



Incompleteness : holes

- Scanning law + selection of sources with > 5 observations



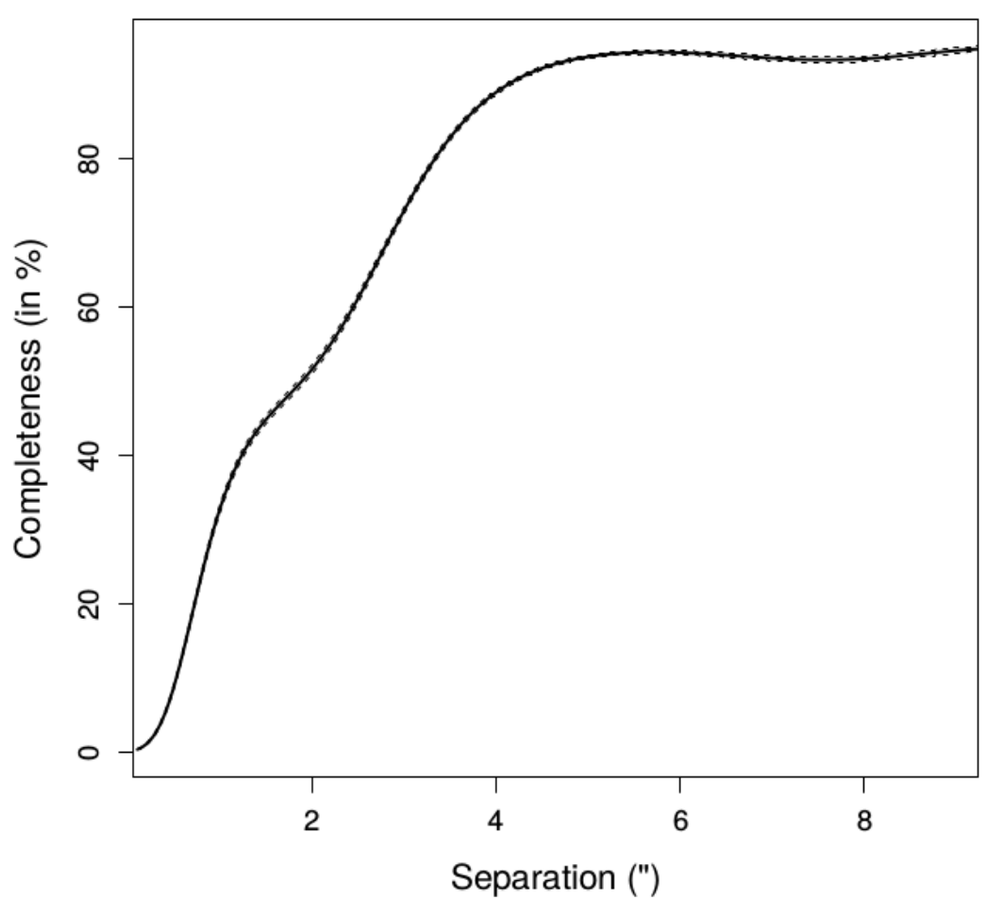
- On-board resources limited on-board for dense regions

Incompleteness: angular resolution

- On-board resolution as expected (HST like)

- In DR1 low separation incompleteness

WDS double stars completeness vs separation

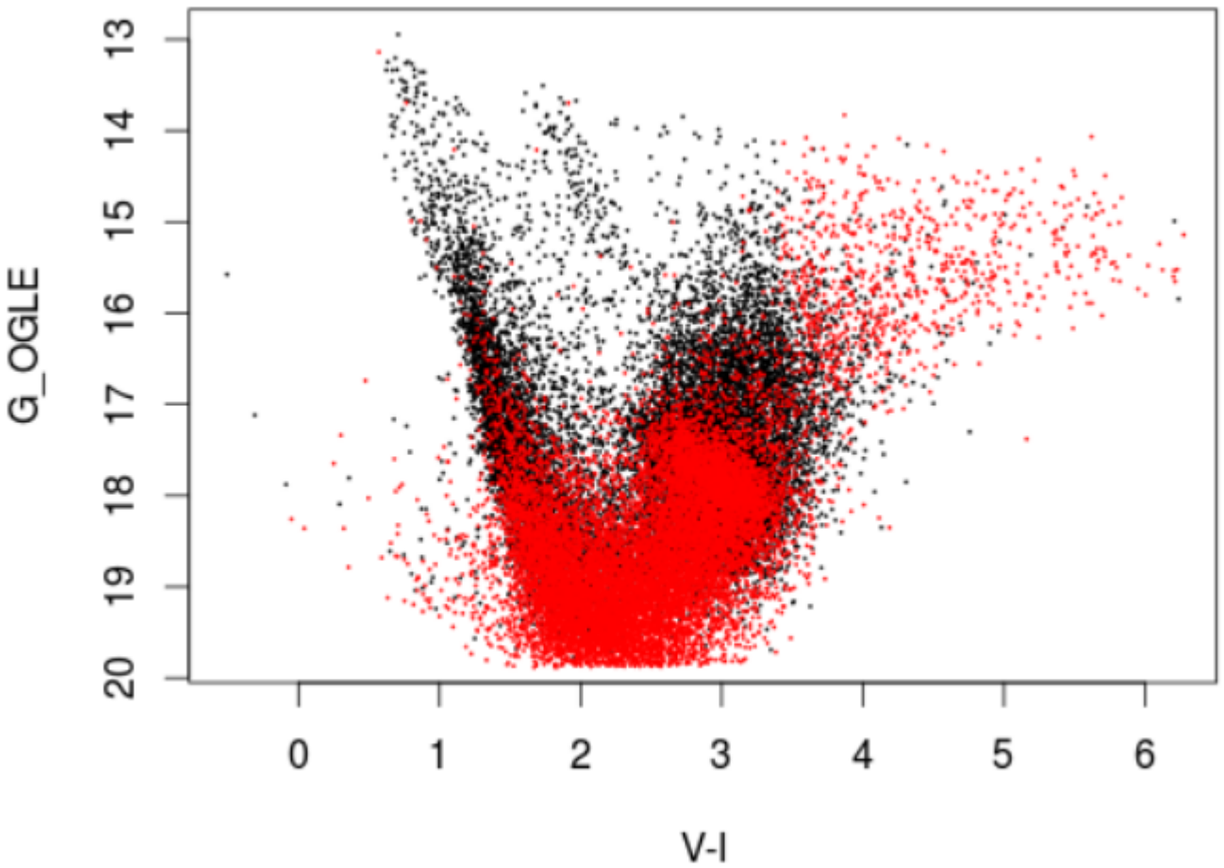


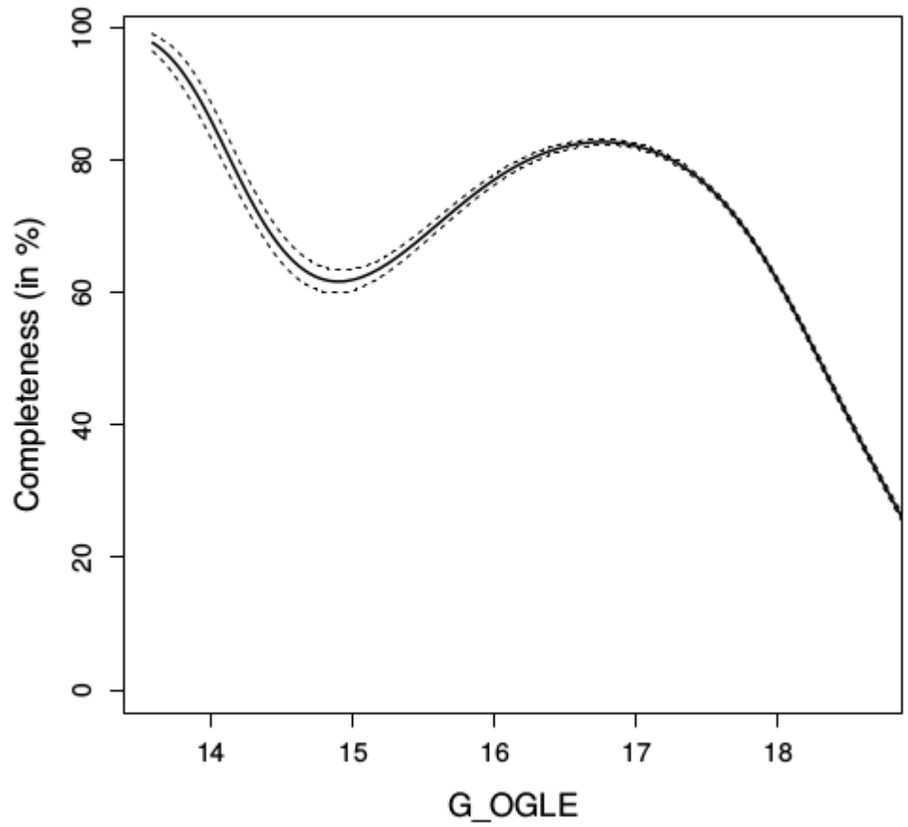
Incompleteness : colour effect

- Very blue and very red stars missing

OGLE bulge field

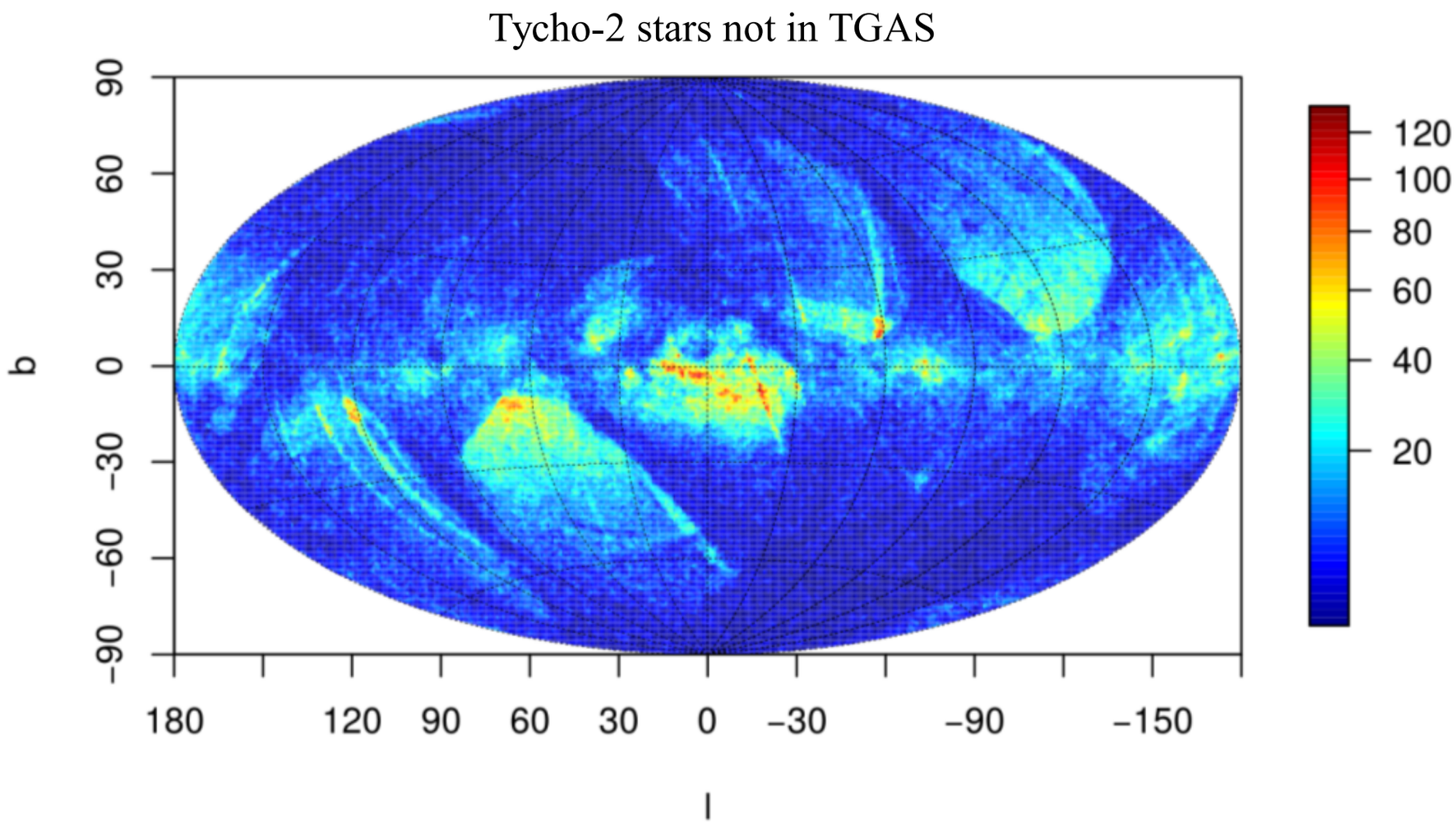
- not found in DR1



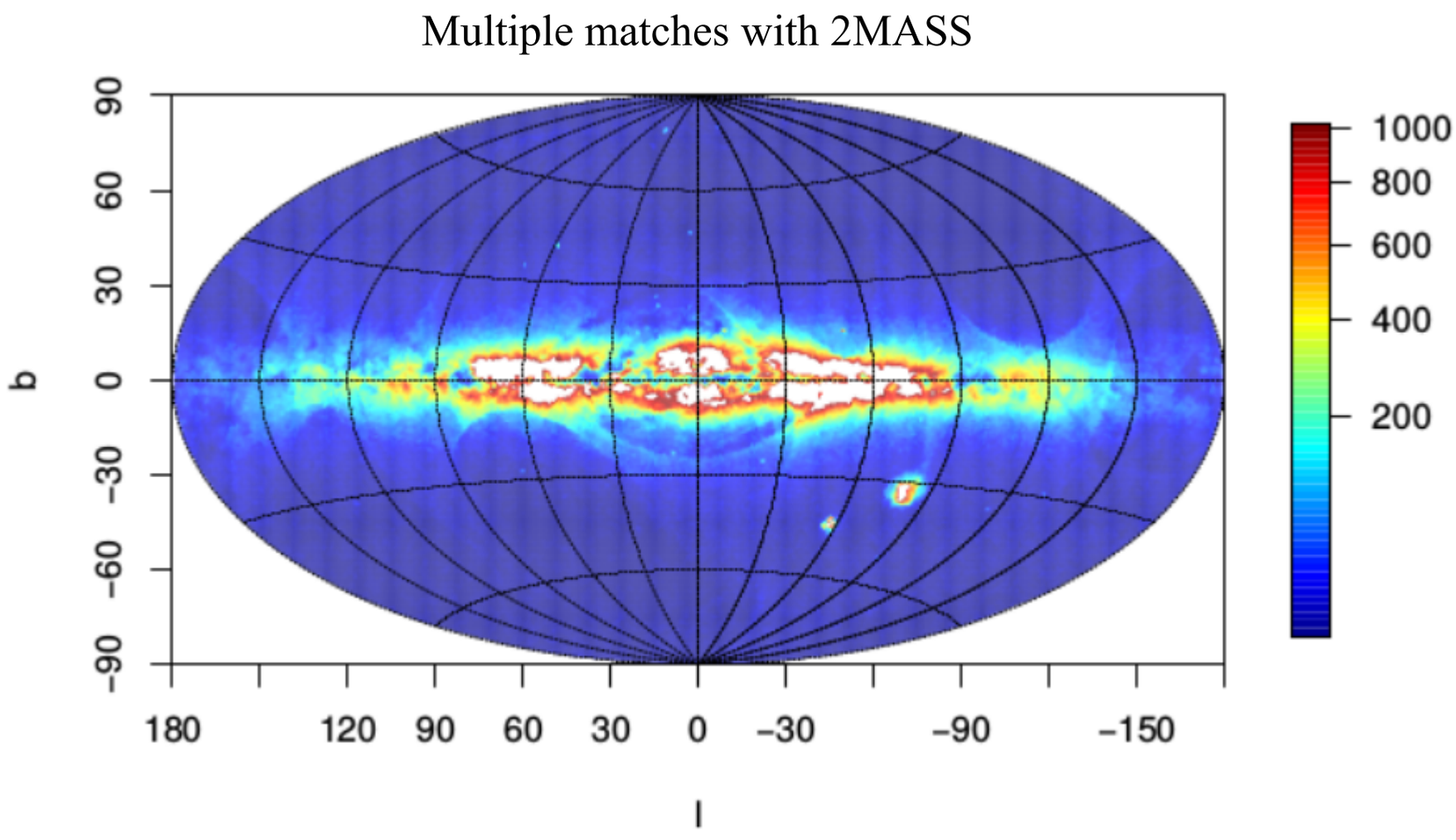


TGAS incompleteness

- Many bright stars missing
- High proper motion stars missing
- Cross-match issues



Duplicated sources remain



TGAS Parallaxes

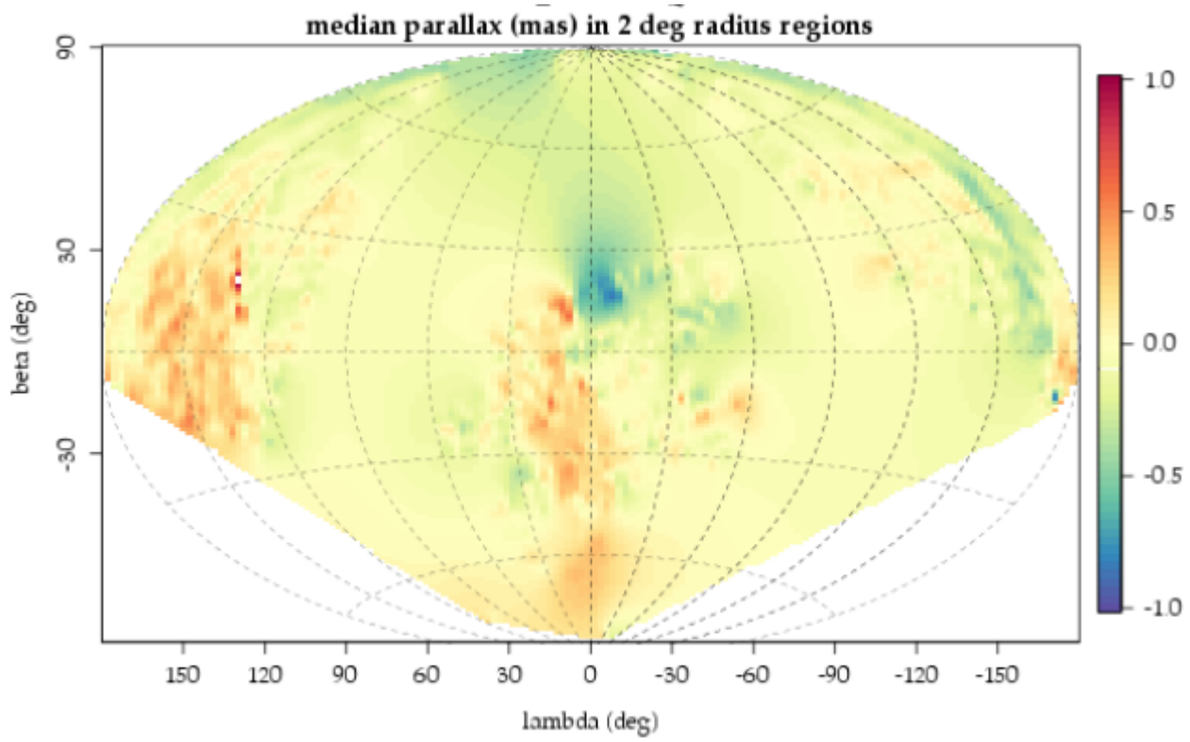
Parallax zero point and uncertainties versus external catalogues

Catalogue	Outliers	ϖ difference	ϖ extra dispersion
Hipparcos	0.09%	-0.094 ± 0.004	0.58 ± 0.005
VLBI	0 / 9	0.083 ± 0.12	-
HST	2 / 19	-0.11 ± 0.19	0.6 ± 0.2
RECONS	0 / 13	-1.04 ± 0.58	-0.9 ± 0.5
VLBI & HST & RECONS	2 / 41	-0.08 ± 0.12	0.42 ± 0.13
Cepheids	0 / 207	-0.014 ± 0.014	-0.18 ± 0.01
RRLyrae	0 / 130	-0.07 ± 0.02	-0.16 ± 0.02
Cepheids & RRLyrae	0 / 337	-0.034 ± 0.012	-0.17 ± 0.01
RAVE	47 / 5144	0.07 ± 0.005	-0.06 ± 0.02
APOGEE	0 / 2505	-0.06 ± 0.006	-0.12 ± 0.01
LAMOST	6 / 317	-0.01 ± 0.02	-0.17 ± 0.02
PASTEL	1 / 218	0.05 ± 0.02	0.1 ± 0.05
APOKASC	0 / 969	-0.07 ± 0.009	-0.15 ± 0.01
LMC	2 / 142	0.11 ± 0.02	-0.14 ± 0.03
SMC	0 / 58	-0.12 ± 0.05	-0.09 ± 0.09
ICRF2 QSO auxiliary solution	1 / 2060	-0.046 ± 0.01	-0.17 ± 0.01

TGAS Parallaxes

QSO auxiliary (5-parameter) solution:

- 10% of the sky with $|\varpi|>0.3$
- Mediane: **-0.04 mas**

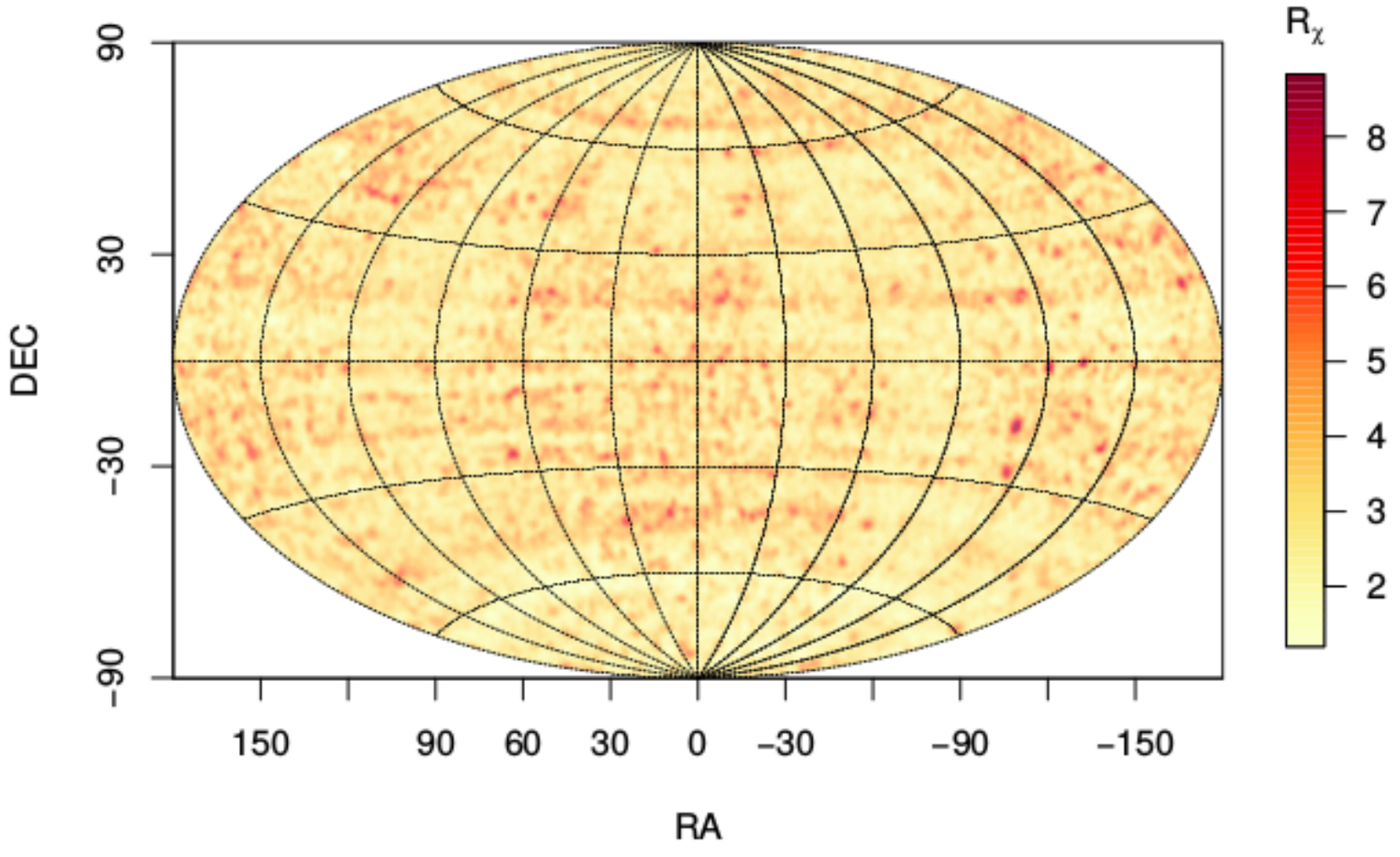


→ local systematics at the same level as the uncertainties :

→ no √N improvement (e.g. clusters...)

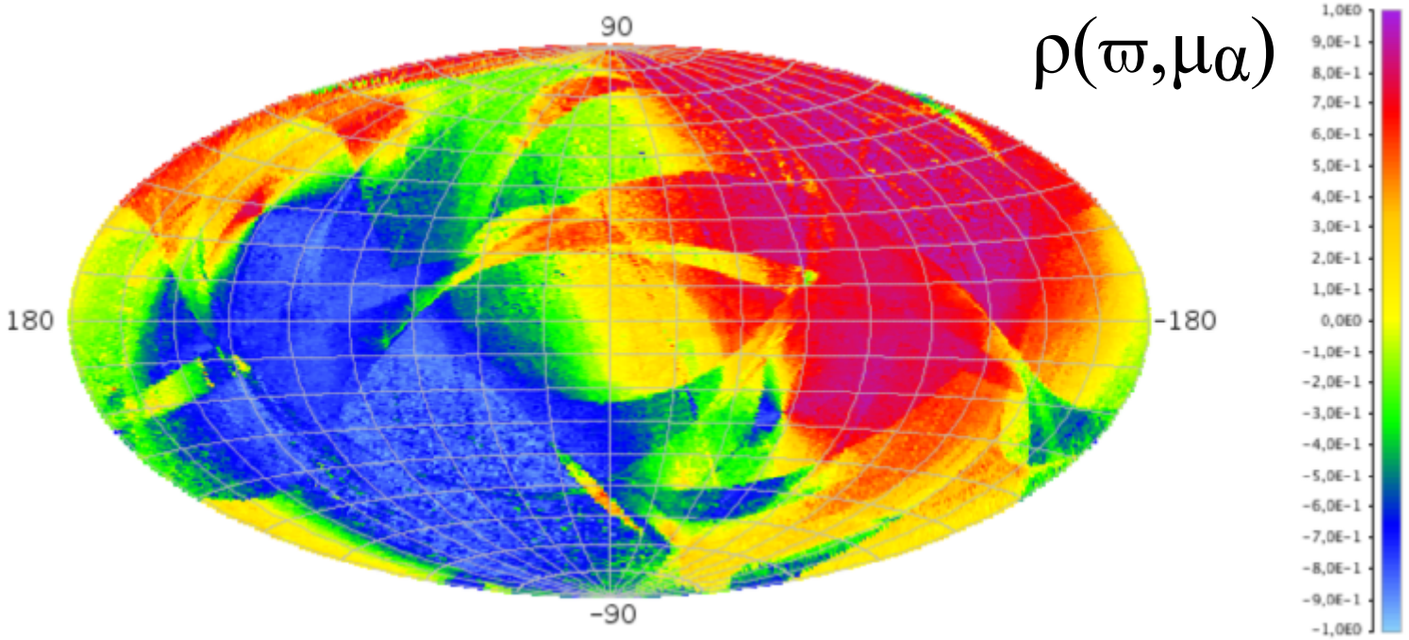
→ $\varpi = x \pm \sigma$ (rand.) **± 0.3 (syst.)** mas

TGAS proper motions versus Tycho-2

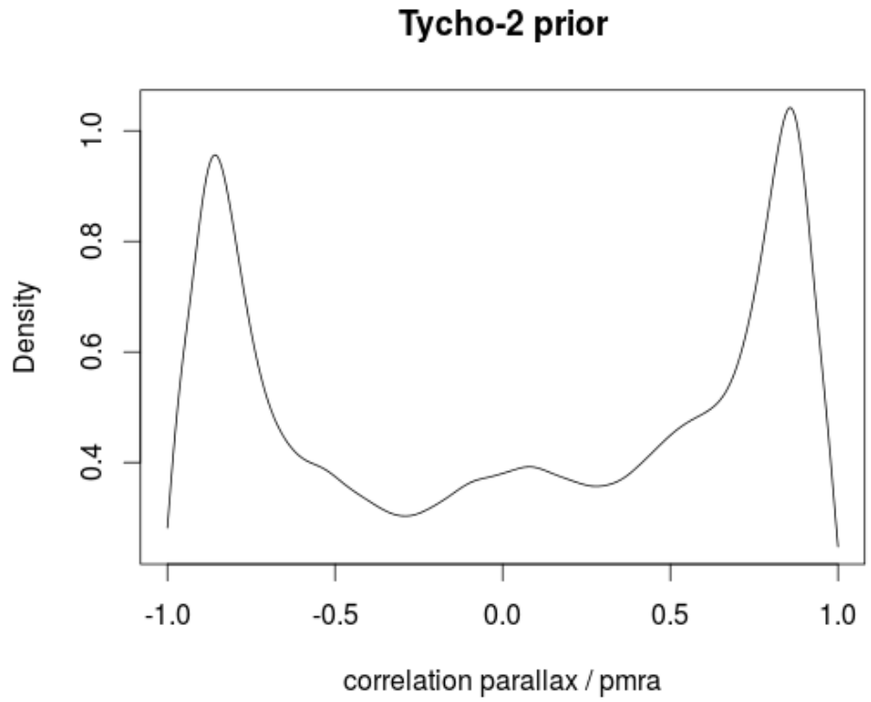


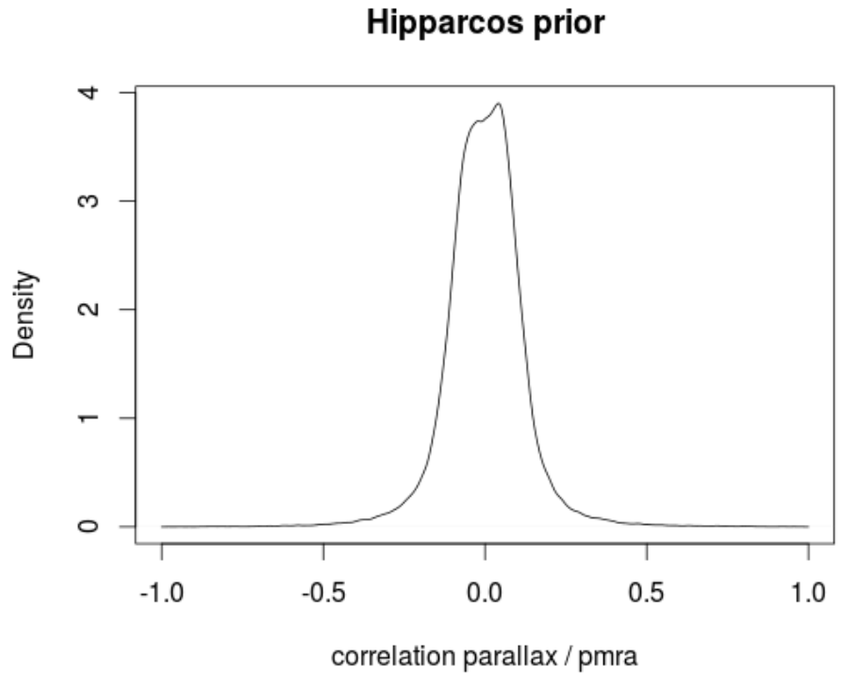
Astrometric correlations

Significant correlations between astrometric parameters need to be taken into account



$\rho(\varpi,\mu_\alpha)$





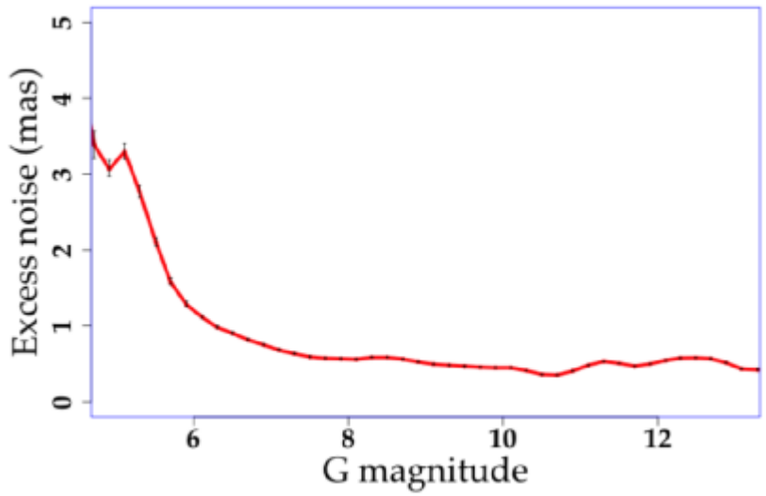
Extra correlations may be missing (attitude/calibration issues)

How to detect problematic stars ?

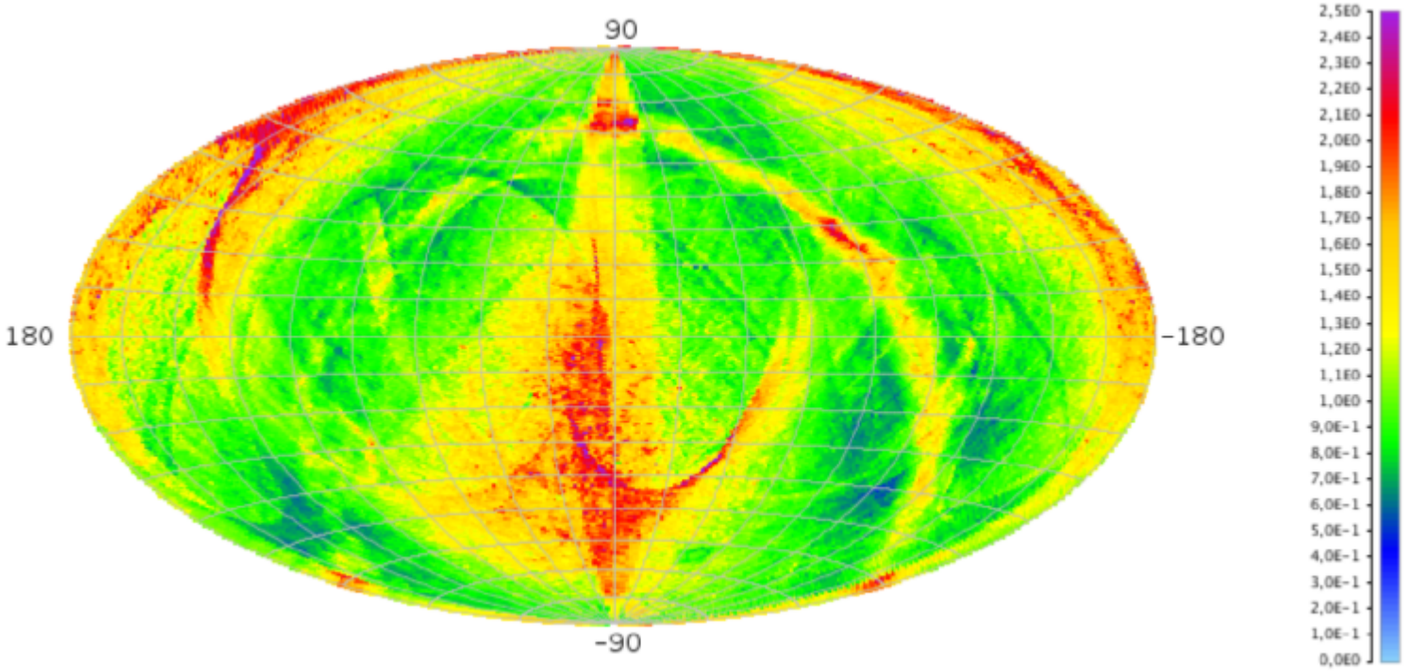
- Binaries
- Visual pairs
- Calibration issues (PSF fit, attitude...)

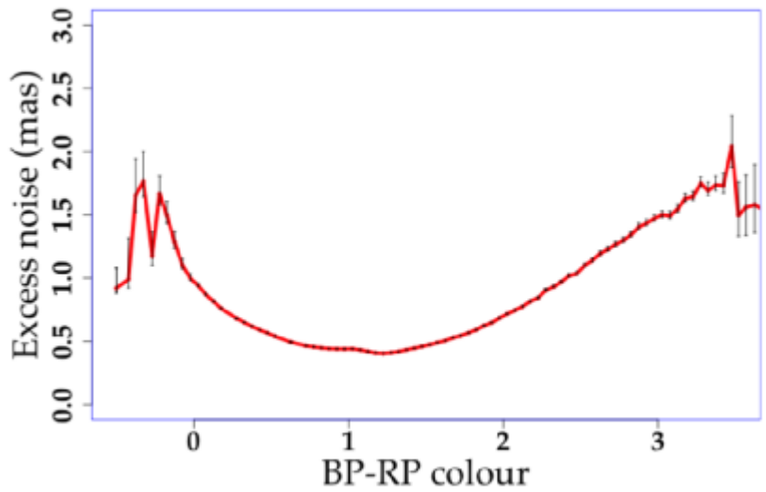
  → excess noise

  → correlations, scanStrenght, nbobs...



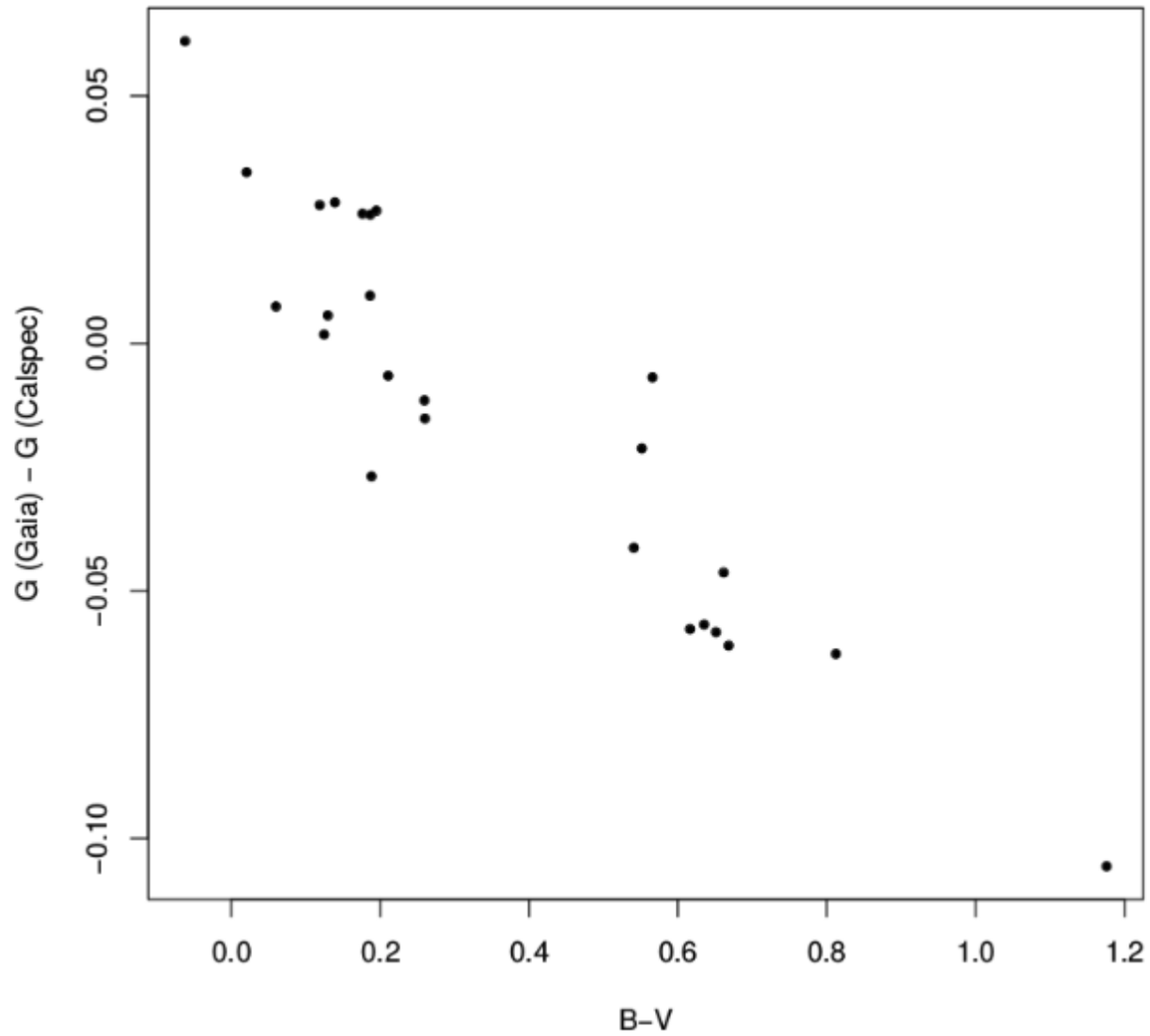
Excess noise





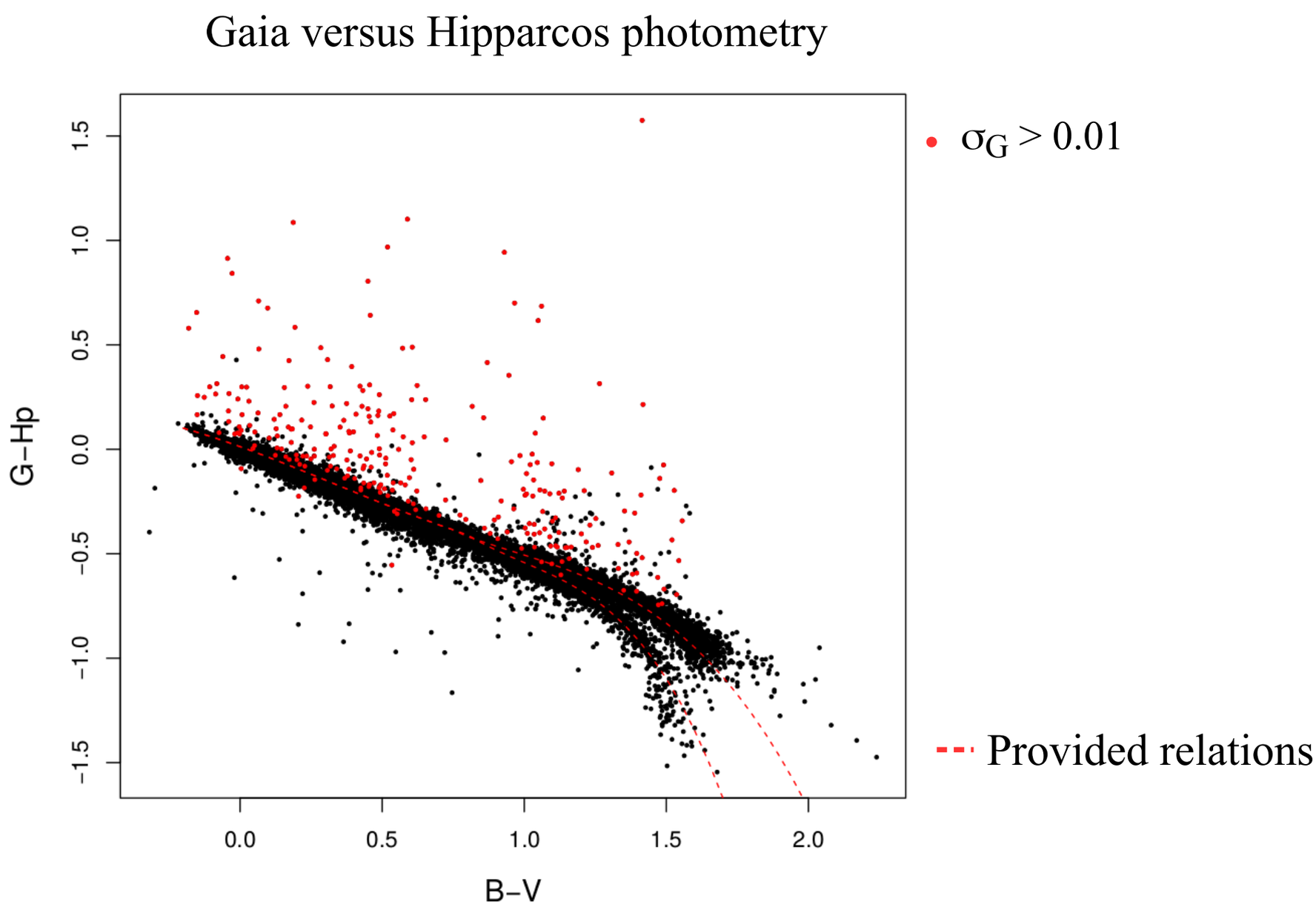
DR1 photometry

- No filter model available for DR1



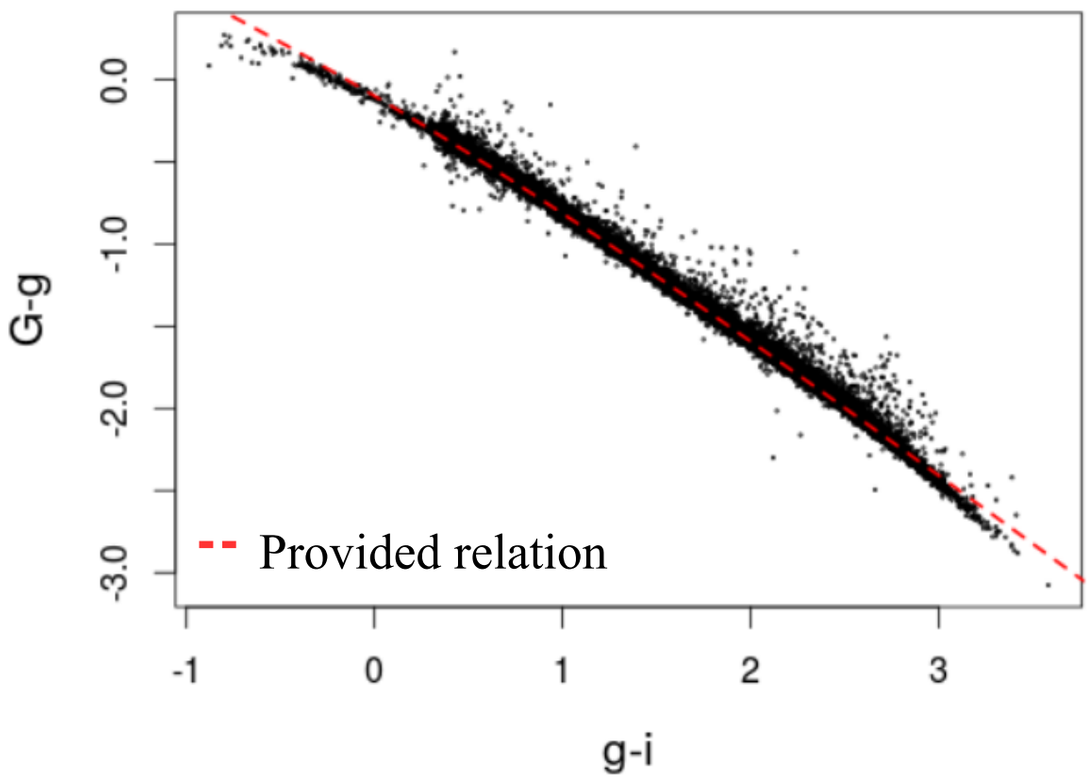
→ photometric transformations provided in the release documentation

DR1 photometric outliers

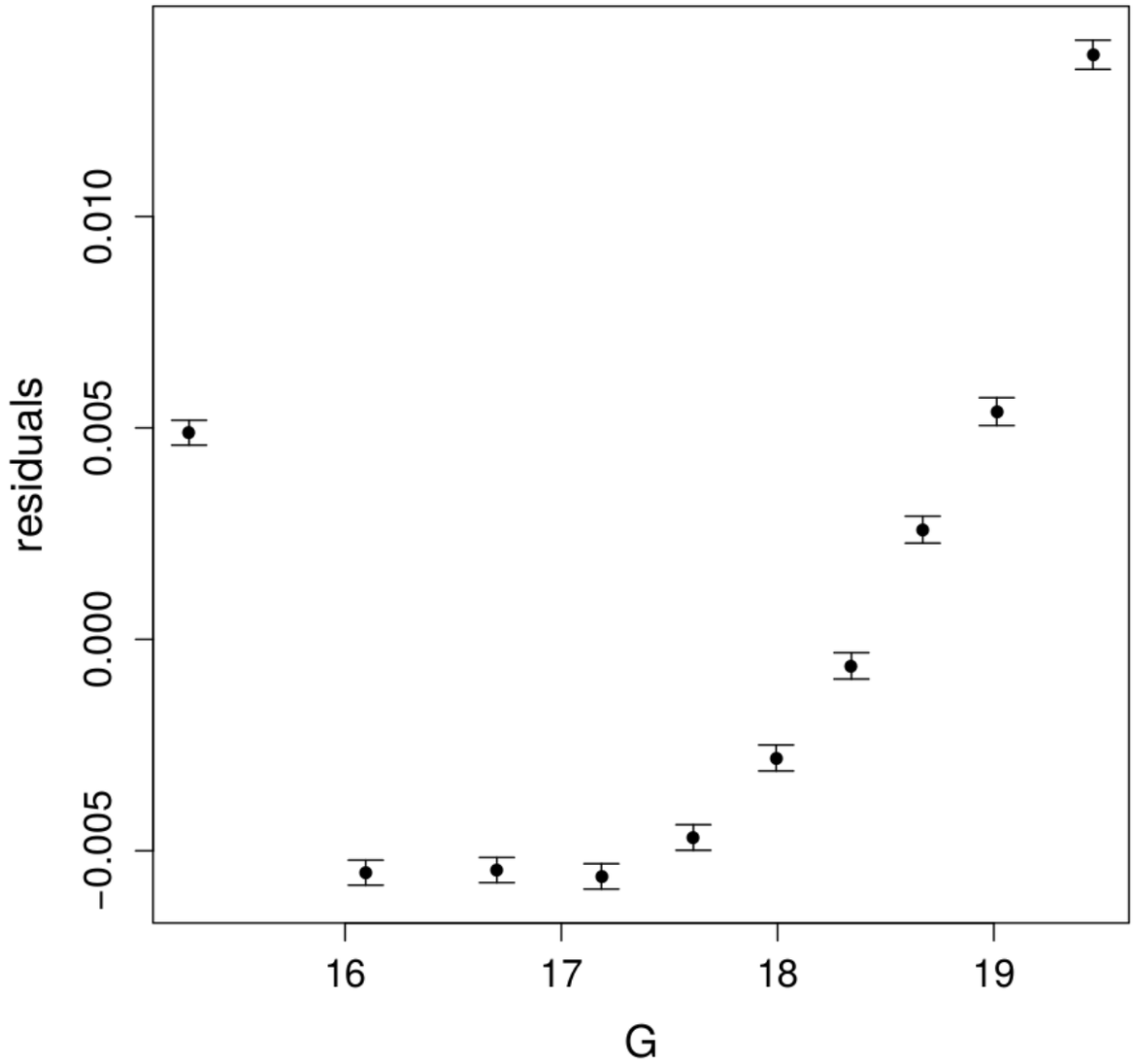


DR1 photometric systematics

Comparison with SDSS tertiary standards of Betoule et al. 2013

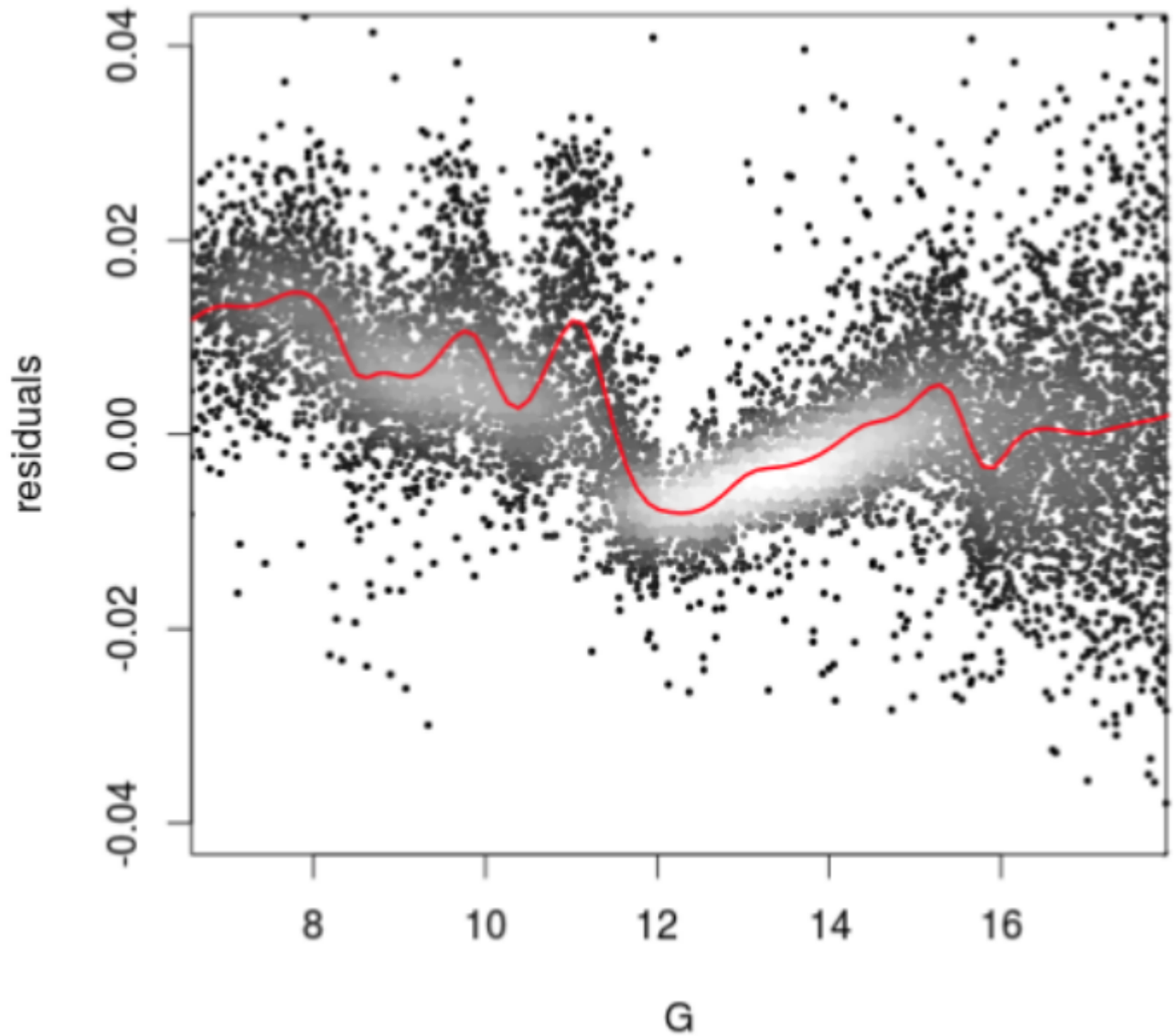


Residuals of G-r from a global G-r=f(g-i) spline



DR1 photometric systematics

Residuals of $G-G_{RP}$ from a global $G-G_{RP}=f(G_{BP}-G_{RP})$ spline



Gaia DR1 Data access

Main portal: `http://archives.esac.esa.int/gaia`

- Online documentation, VO compatible, TAP interface, visualization apps
- Pre-computed cross-match to large catalogues: UCAC4, 2MASS, SDSS, GSC2, WISE, PPMXL, URAT1

  +

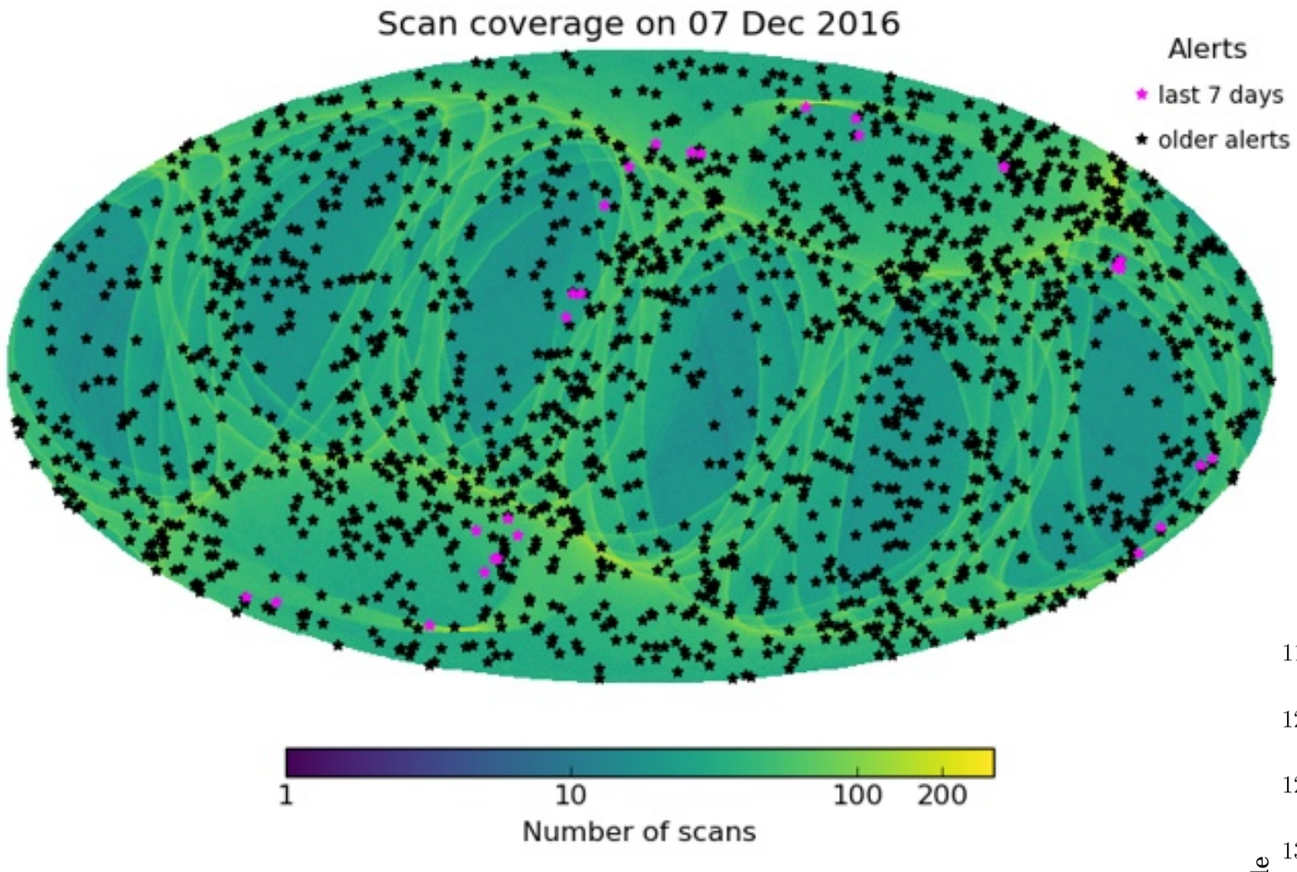
- Fast visualization and analysis entire DR1: `http://vaex.astro.rug.nl`
- Command line access: `https://pypi.python.org/pypi/pygacs`

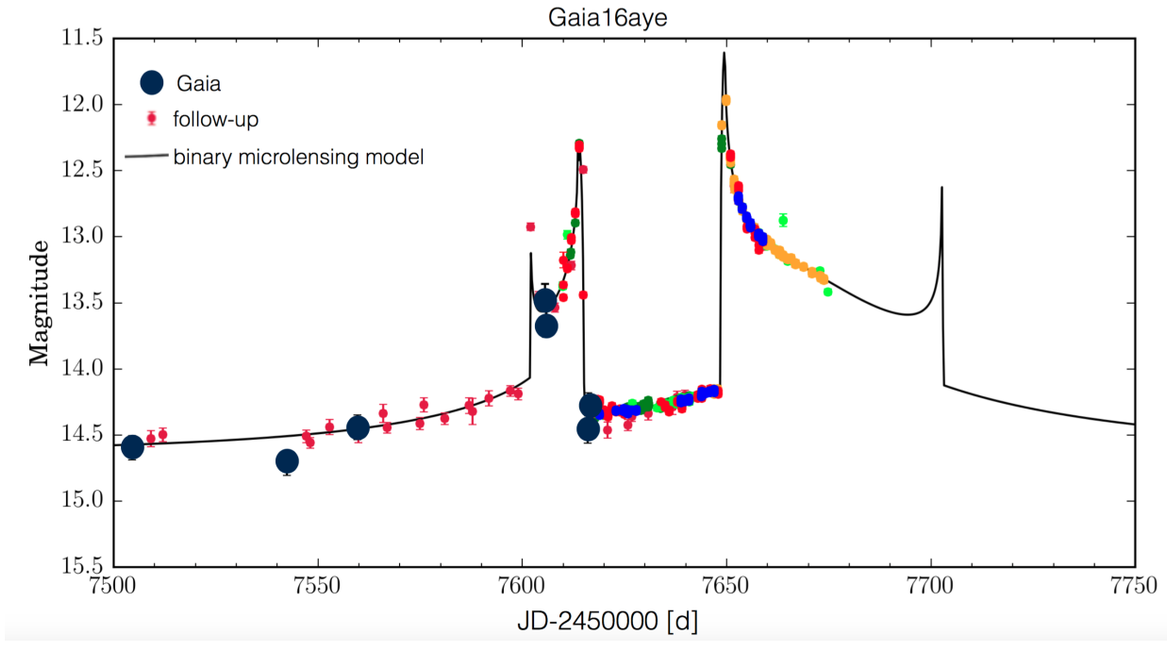
Partner data centres

- CDS: `http://cds.unistra.fr/gaia`
- ASDC: `http://gaiaportal.asdc.asi.it`
- ARI: `http://gaia.ari.uni-heidelberg.de`
- AIP: `http://gaia.aip.de`

Gaia Photometric Science Alerts

started publishing alerts in July 2014

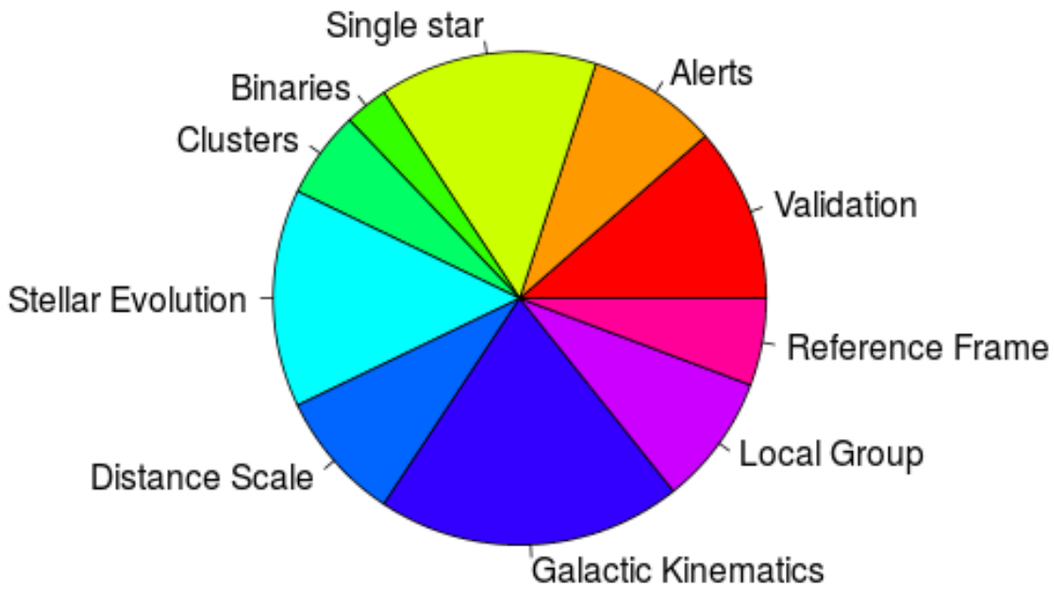


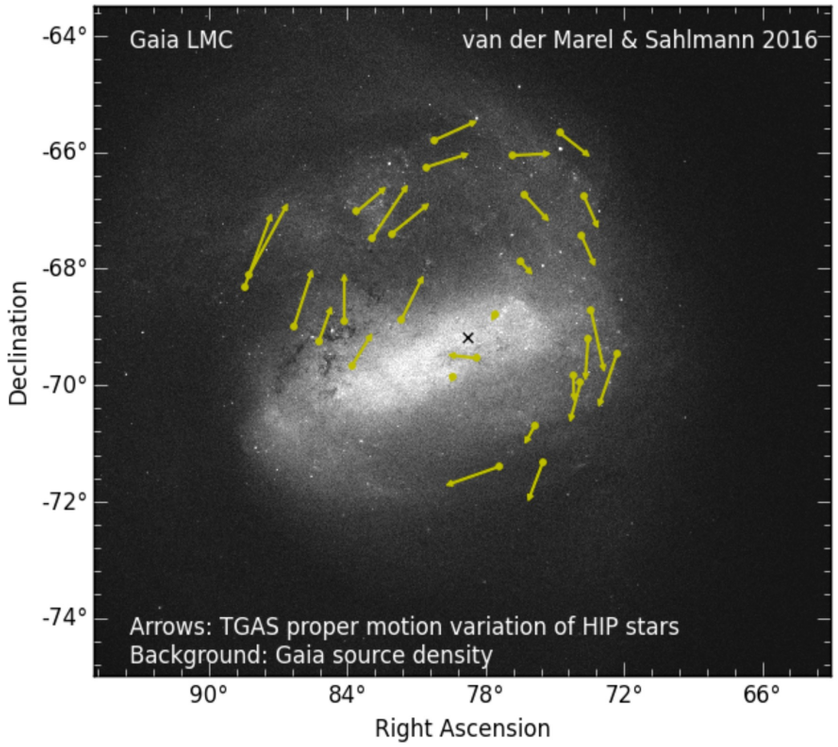


http://gsaweb.ast.cam.ac.uk/alerts

Gaia DR1 – the first applications

More than 43 papers in 2 months using the Gaia data (astro-ph)





Gaia DR1 - conclusion

- Significant increase in the amount and precision of astrometry and photometry

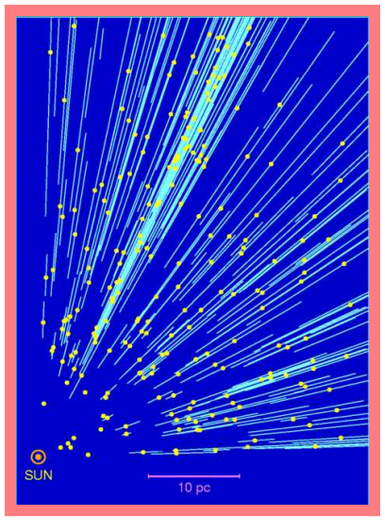
- Preliminary data with issues to take into account in the exploitation
  - Gaia on-line documentation
  - Arenou et al. 2016, submitted

- Major improvements already planned for DR2 in ~ 1 year:
  - 1 billion parallaxes and proper motions (22 months of data)
  - Photometry $G/G_{BP}/G_{RP}$
  - Radial velocity for the brightest stars
  - …

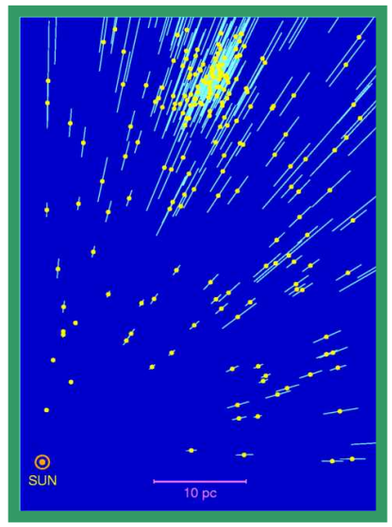
More than yesterday, less then tomorrow...

	Hipparcos	Gaia
Magnitude limit	12 mag	20.7 mag
Completeness	7.3 – 9.0 mag	20 mag
Bright limit	0 mag	3 mag
Number of objects	120,000	47 million to G = 15 mag 1.2 billion to G = 20 mag
Effective distance limit	1 kpc	50 kpc
Quasars	1 (3C 273)	500,000
Galaxies	None	1,000,000
Accuracy	1 milliarcsec	5-16 μarcsec at G = 10 mag 26 μarcsec at G = 15 mag 600 μarcsec at G = 20 mag
Photometry	2-colour (B and V)	Low-res. spectra to G = 20 mag
Radial velocity	None	15 km s^{-1} to G_{RVS} = 16 mag
Observing	Pre-selected	Complete and unbiased

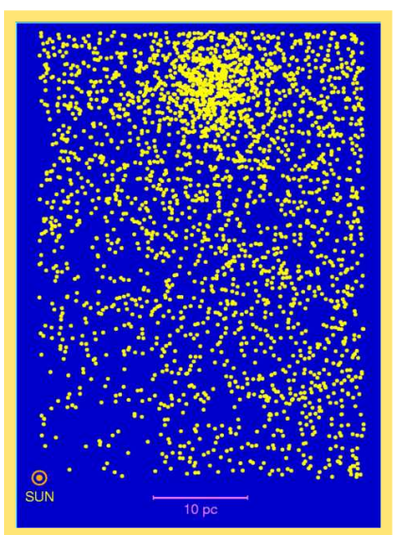
Hyades



1960



1990



2022