Gaia: Mission, Status, Contents of Data Release 1

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Gaia DR1 video by Klaus Jäger and Stefan Jordan
Gaia's First Data Release

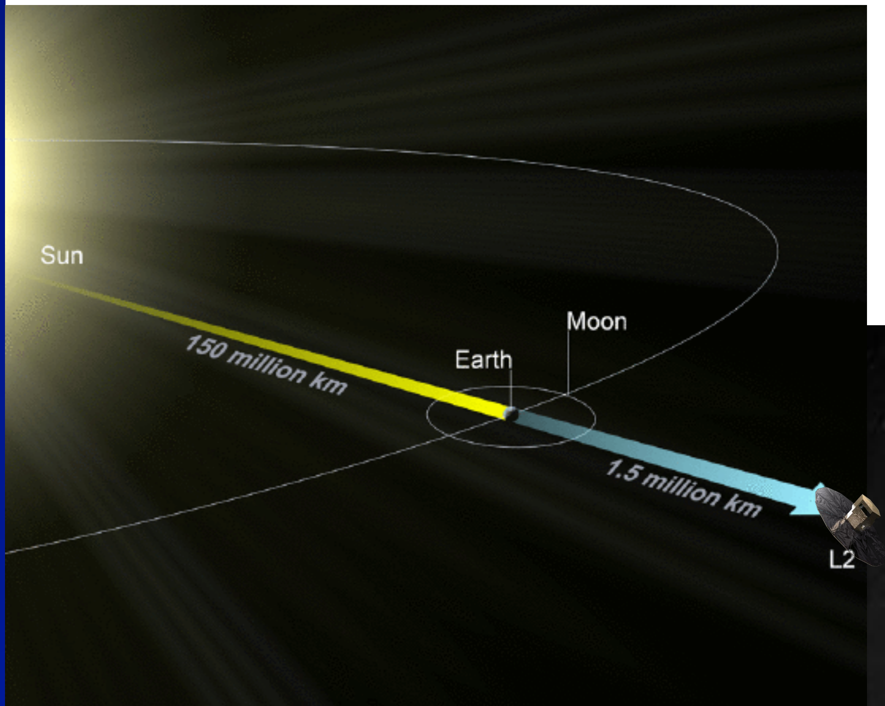
Available on Youtube: https://youtu.be/2Z_O66Z4I6Y

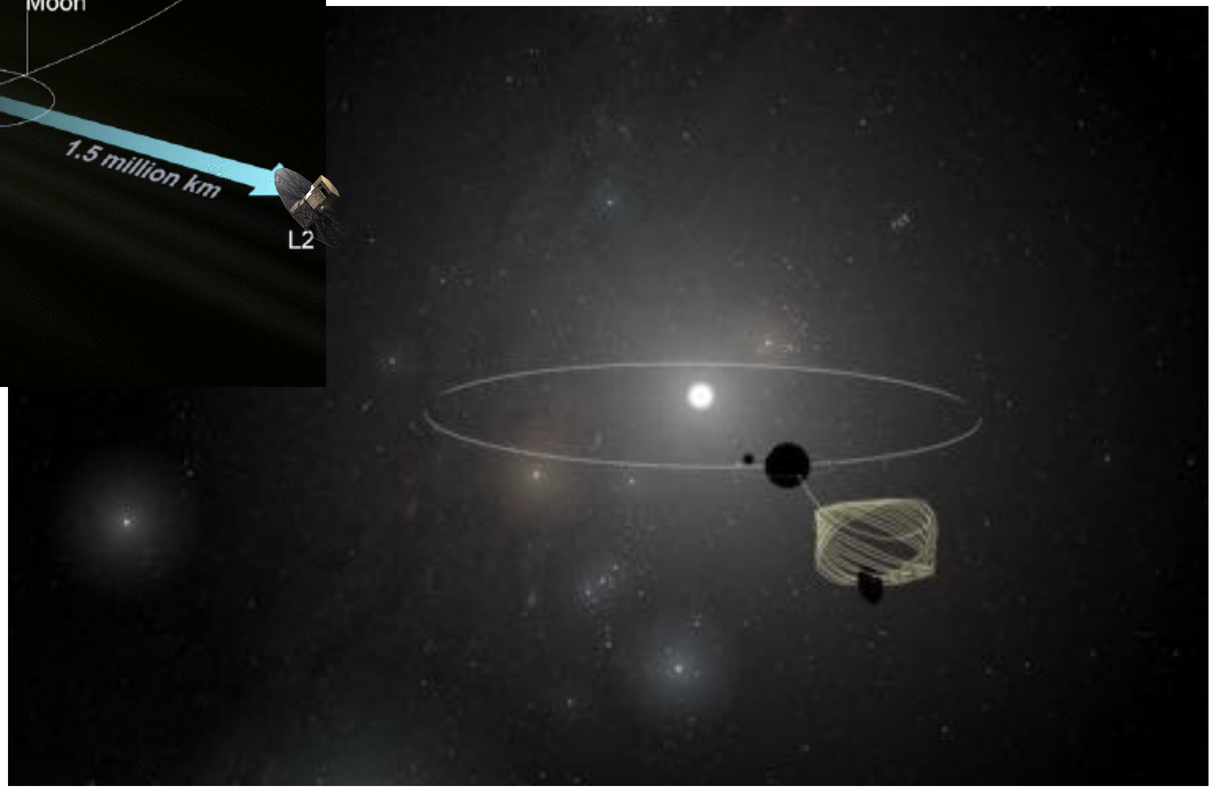
The Launch

- **Soyuz-Fregat**
- 47 m high
- Sinnamary in French Guyana
- Launch date: 19. Dezember 2013

Gaia at L2

Animation with Gaia Sky:
Toni Sagristà Sellés
(ARI/ZAH University
of Heidelberg)
Software downloadable at
https://zah.uni-heidelberg.de/gaia/outreach/gaiasky/



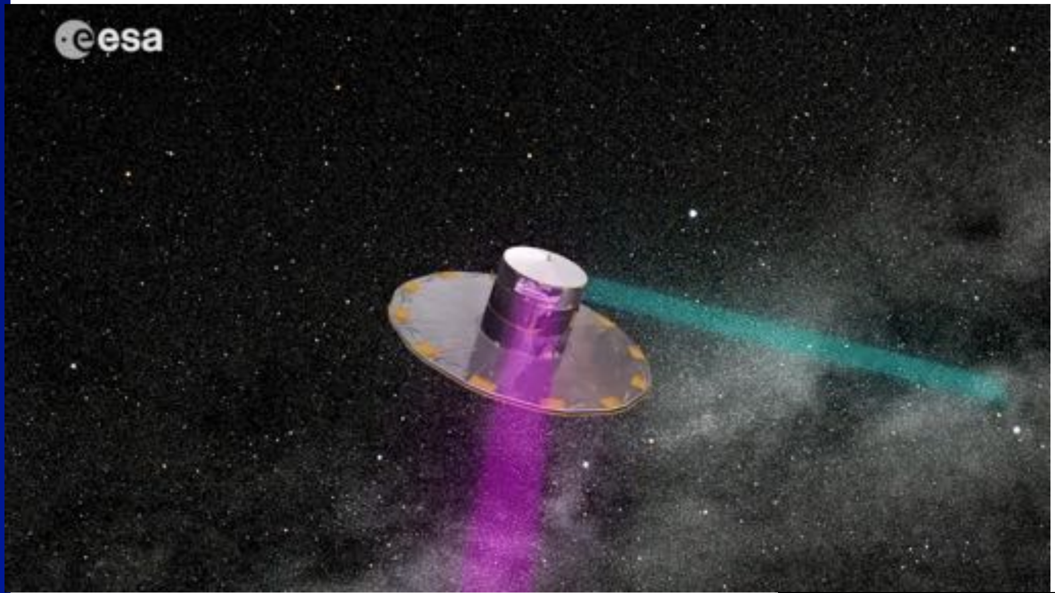


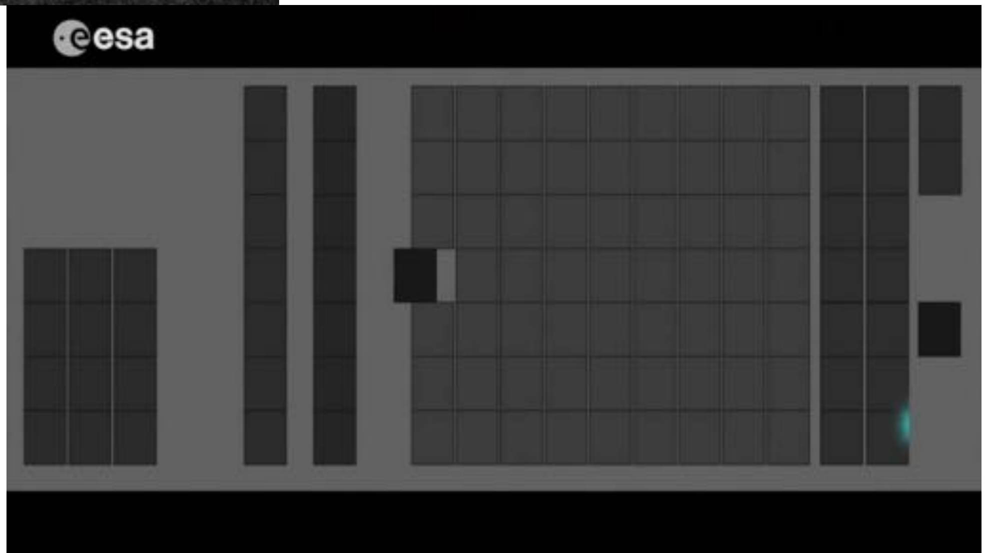
Gaia's schedule

- **1993:** First proposal to ESA
- **2000:** accepted as „Cornerstone Mission“
- **Launch:** December 19, 2013
- **End of commissioning:** July 18, 2014
- **September 14, 2016, 12:30 CEST:** Gaia DR1
- **April 2018:** Gaia DR2
- **2019:** End of nominal measurements (5 years)
- **2022/2023:** Publication of final catalogue?

- Estimated end of mission due to cold gas exhaustion end-2023 ±1 year

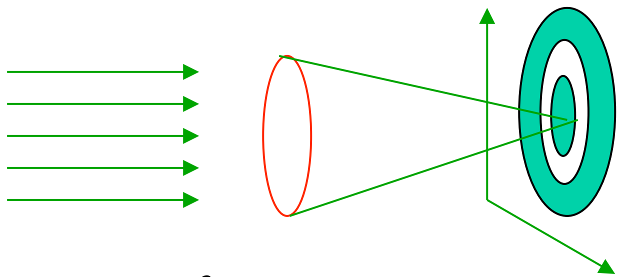
Scanning, Focal plane

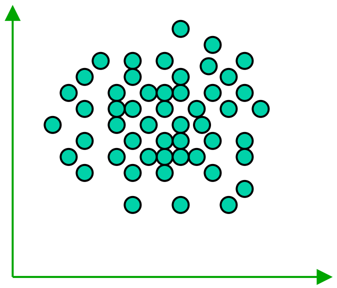




Astrometric precision

Astrometric precision ≠ Spatial resolution





$$\sigma \approx \frac{\lambda}{D}\frac{1}{\sqrt{N}}$$

Centroid

N = Number of collected photons

λ=0.5µm, D=1.45 m

G=15 mag $\Rightarrow$ N=6 $\cdot 10^7$

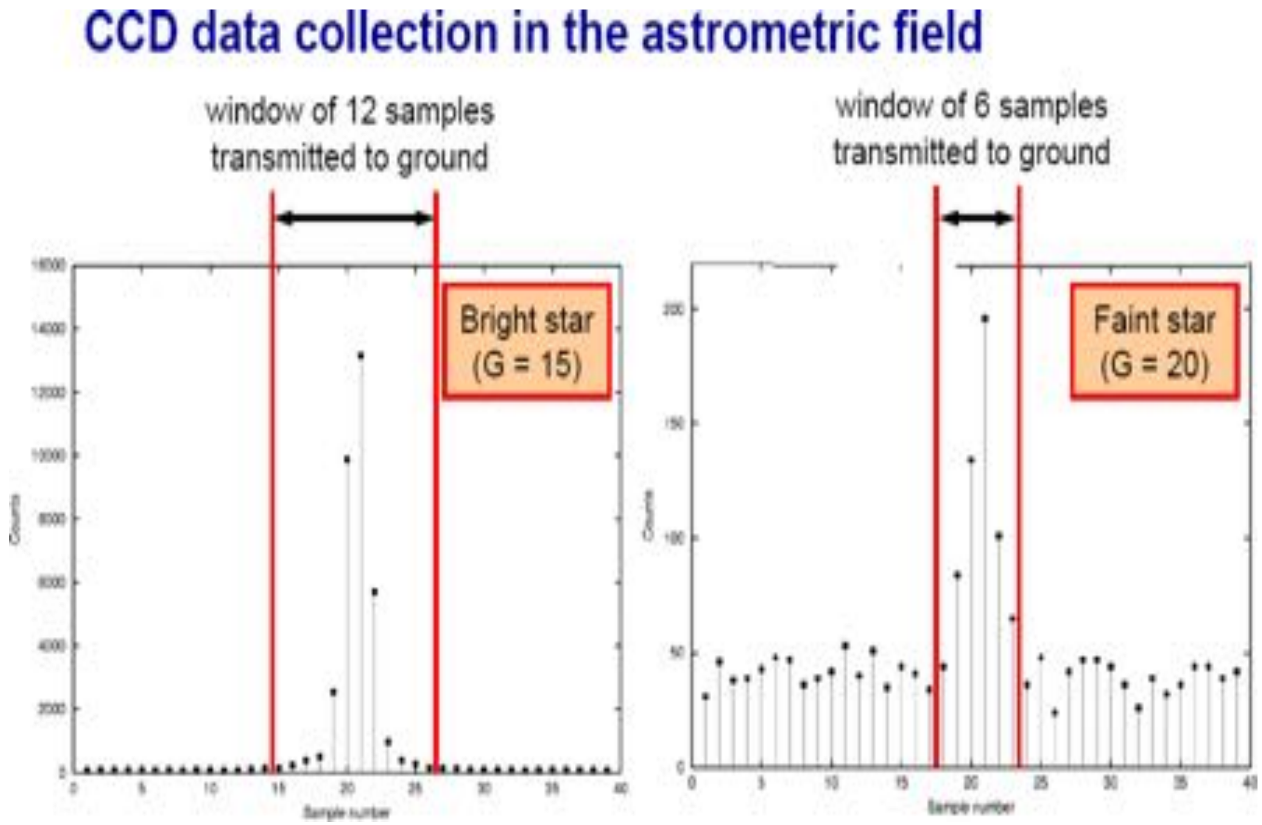
σ=0.5 $\cdot 10^{-6}$/(1.45*7700)≈10µas

Including other error sources

σ≈25µas

Across-scan accuracy about a factor of 10 smaller

Elementary observations



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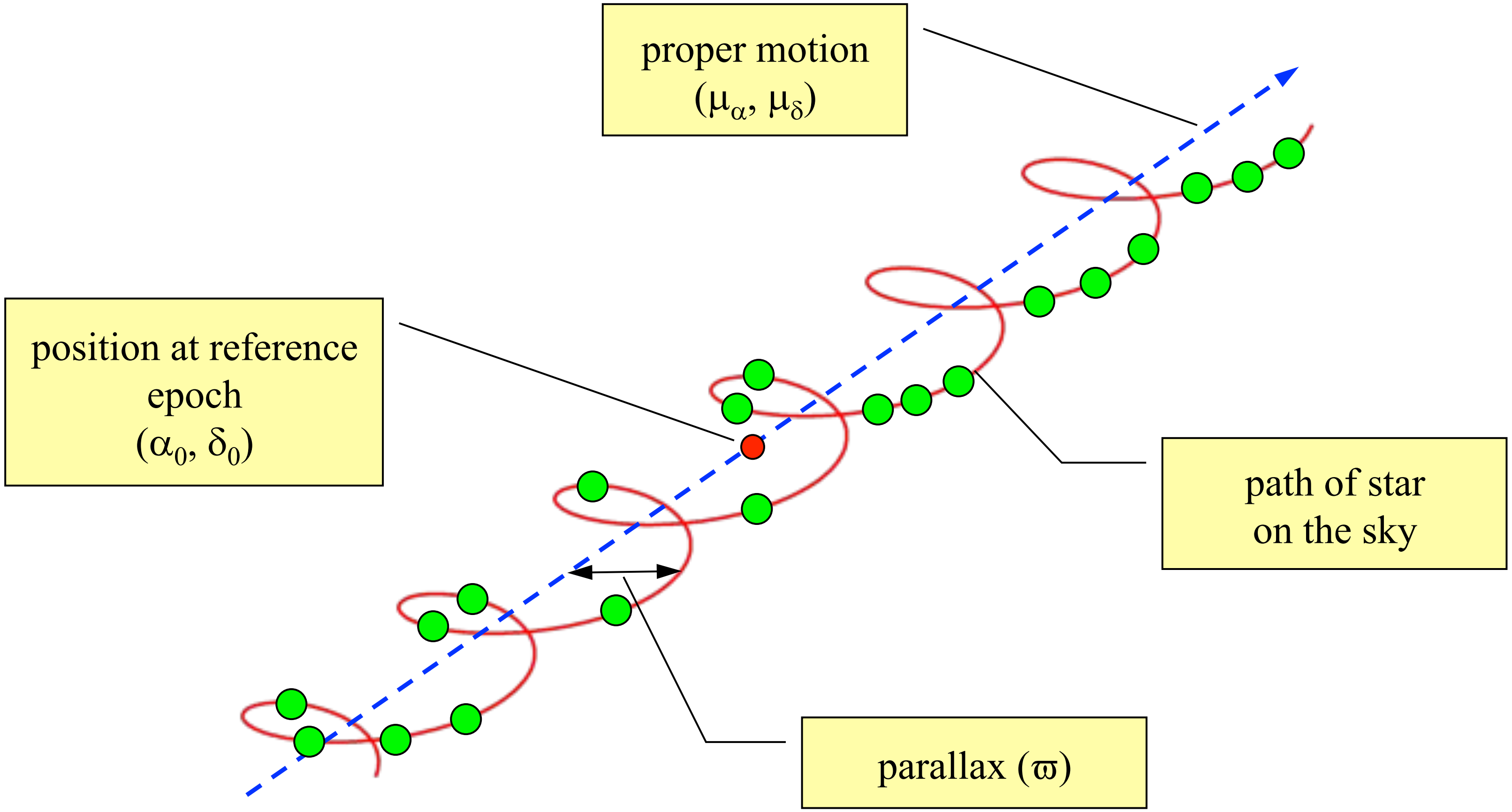
Over the mission, every source (star, QSO, asteroid, ...) will be observed
~ 600 times in the along-scan (AL) direction (timing data, *t*)
~ 70 times in the across-scan (AC) direction (pixel coordinate, *p*)
These are the "elementary astrometric observations" of the source

How do stars move? 5 parameters



The standard astrometric model for “stars”

- In the standard astrometric model, the Gaia source is assumed
  - to be a point source (more precisely: have a well-defined photocentre), and
  - to move through space at constant velocity relative to the Solar System Barycentre

- This is probably a good approximation for >80% of unresolved Gaia sources beyond the Solar System (and for many resolved sources)

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- This is probably a good approximation for >80% of unresolved Gaia sources beyond the Solar System (and for many resolved sources)
- In Gaia DR1 the standard astrometric model is used for all non-solar system objects (stars, binaries, AGNs, ...)
- Deviations are indicated by the astrometric excess noise (explained later)

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- (Future Gaia DRs will use more specialised models for some sources - not discussed here)

Kinematic and astrometric parameters

- Point source ⇒ well-defined barycentric position vector $r(t)$
- Uniform velocity ⇒ $r(t) = r_0 + (t - t_0)v$

- Kinematic model:
- - reference time t_0 and six kinematic parameters x_0, y_0, z_0, v_x, v_y, v_z
- Astrometric model:

  - reference epoch t_{ep} and six astrometric parameters α, δ, ϖ, $\mu_{\alpha*}$, μ_δ, v_r
- The two sets of parameters are in principle equivalent, but:

t_0, x_0, y_0, z_0, v_x, v_y, v_z

trivial and always possible - note: $t_{ep} = t_0 + |r_0|c^{-1}$ ↓

↑ difficult, and not always possible (e.g. when $\varpi \leq 0$)

t_{ep}, α, δ, ϖ, $\mu_{\alpha*}$, μ_δ, v_r

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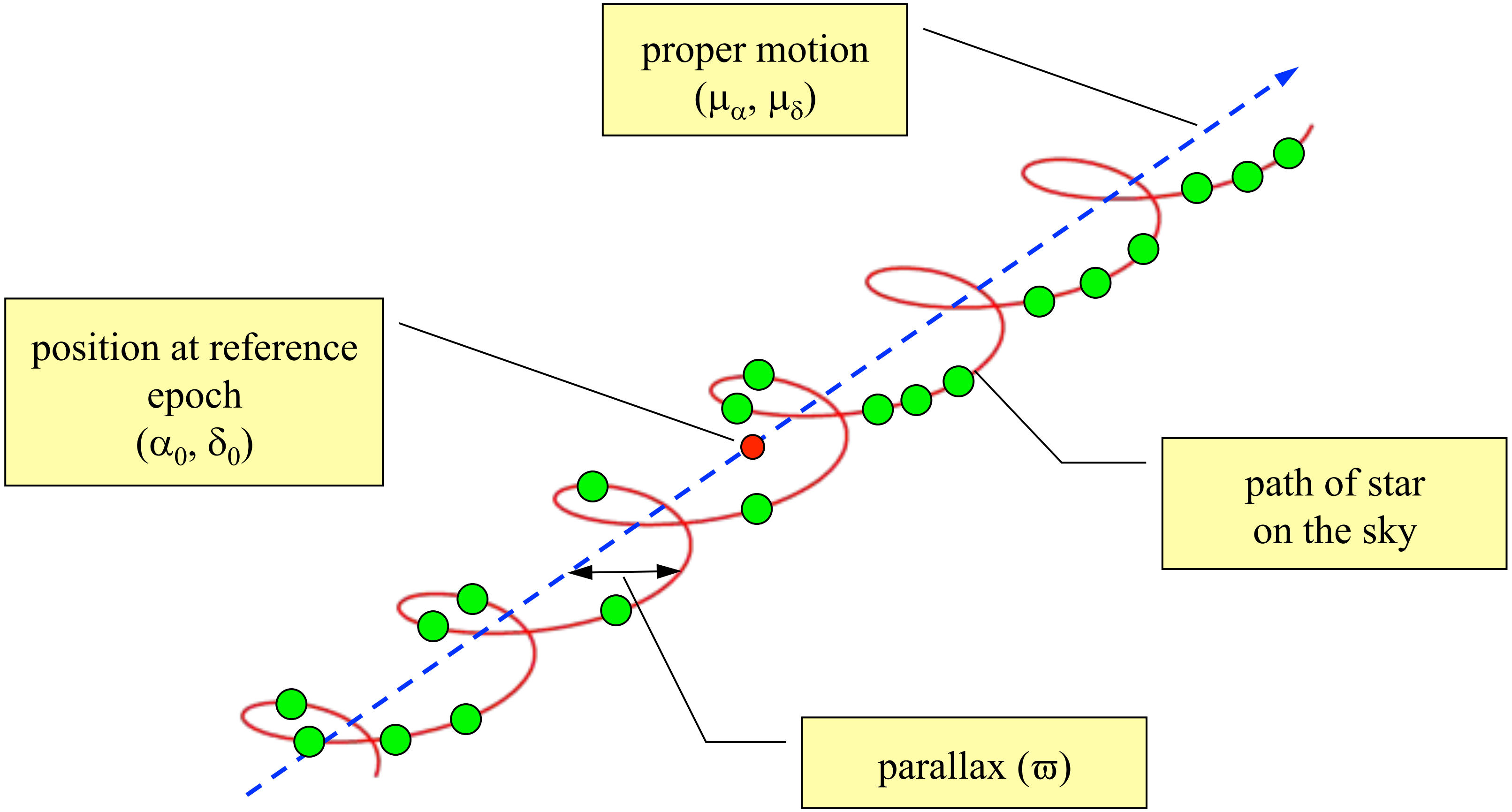
How do stars move? 5 parameters



Gaia ‘s data reduction problem

With the same accuracy with which Gaia

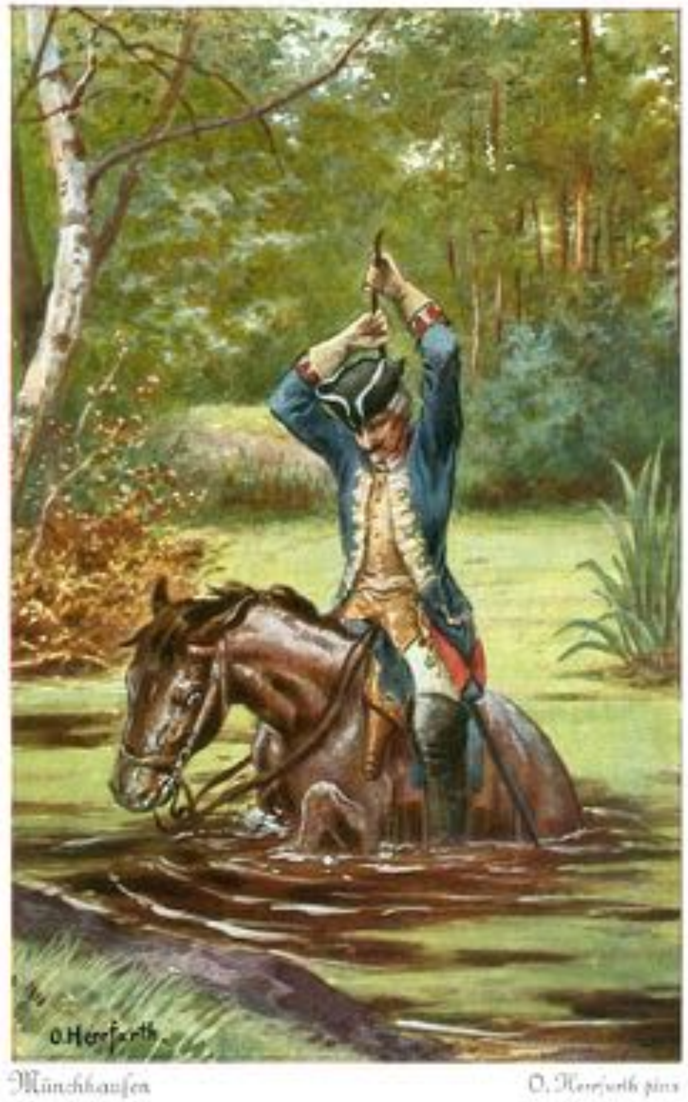
- measures position of stars,

it is necessary to know

- where Gaia is pointing at (attitude), where Gaia is, how fast it is,

how exactly

- the optic and detectors are aligned
- and, whether Einstein was fully right!!



Astrometric data reduction

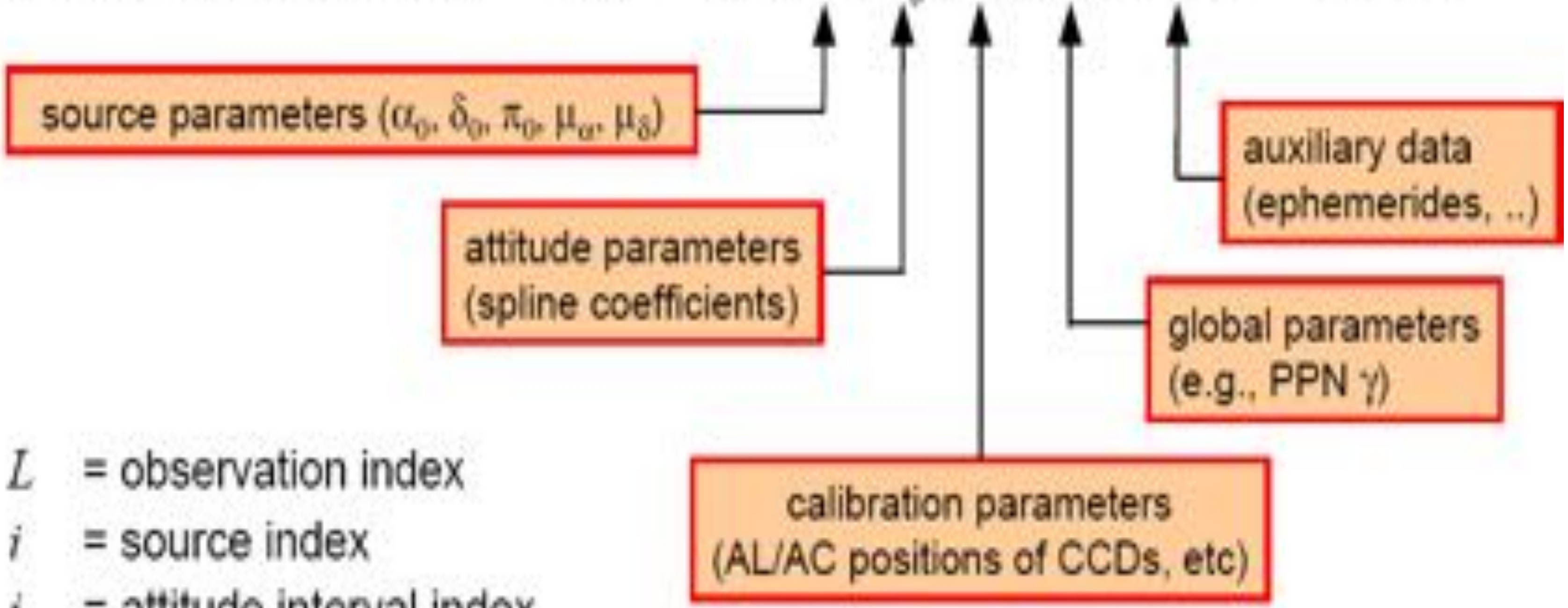
- 10^{12} individual measurements
- $5 \cdot 10^{9}$-10^{10} unknowns
- The unknowns are strongly correlated with each other

- 5000 million astrometric parameters
- 150 million unknowns for the attitude
- 10-50 million other calibration parameters

Model of elementary astrometric observations

Along-scan observation: $t_L = f_{\mathrm{AL}}(s_i, a_j, c_k, g, \mathrm{aux}) + \mathrm{noise}$

Across-scan observation: $p_L = f_{\mathrm{AC}}(s_i, a_j, c_k, g, \mathrm{aux}) + \mathrm{noise}$



L = observation index
i = source index
j = attitude interval index
k = calibration unit index

Database knows the mappings $L \leftrightarrow i$, $L \leftrightarrow j$, $L \leftrightarrow k$

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Gaia VO Day, TU Berlin, March 2-3, 2017

Observation equations

Gaia DPAC

- Provisional values of the source, attitude, calibration and global parameters allow us to ***predict*** the values of *t* and *p* from the model.
- The differences between the ***observed*** and ***predicted*** values allow us to ***correct*** the provisional parameter values, using the least-squares method.
- Linearisation gives the observation equations

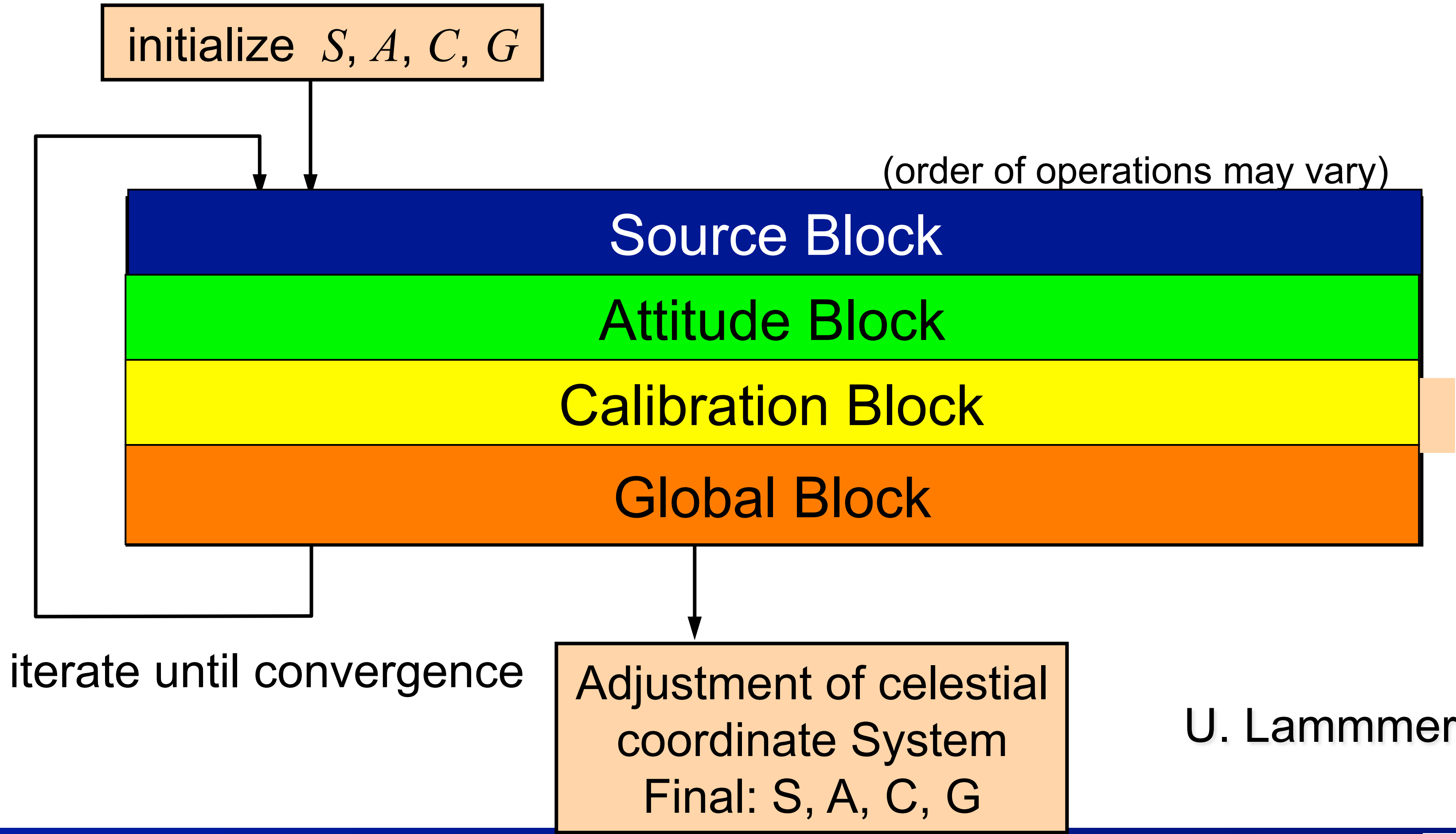
$$t_L^{(\mathrm{obs})} - t_L^{(\mathrm{pred})} = \frac{\partial f_{\mathrm{AL}}}{\partial \boldsymbol{s}_i} \Delta \boldsymbol{s}_i + \frac{\partial f_{\mathrm{AL}}}{\partial \boldsymbol{a}_j} \Delta \boldsymbol{a}_j + \frac{\partial f_{\mathrm{AL}}}{\partial \boldsymbol{c}_k} \Delta \boldsymbol{c}_k + \frac{\partial f_{\mathrm{AL}}}{\partial \boldsymbol{g}} \Delta \boldsymbol{g} + \mathrm{noise}$$

(and similarly for *p*).

- Solving these equations for a subset (~10^8) of well-behaved ("primary") sources
- → corrections (updates) Δ***s***, Δ***a***, Δ***c***, Δ***g***.
- The model is only weakly non-linear, so a complete solution of these equations should give the desired solution in one go.

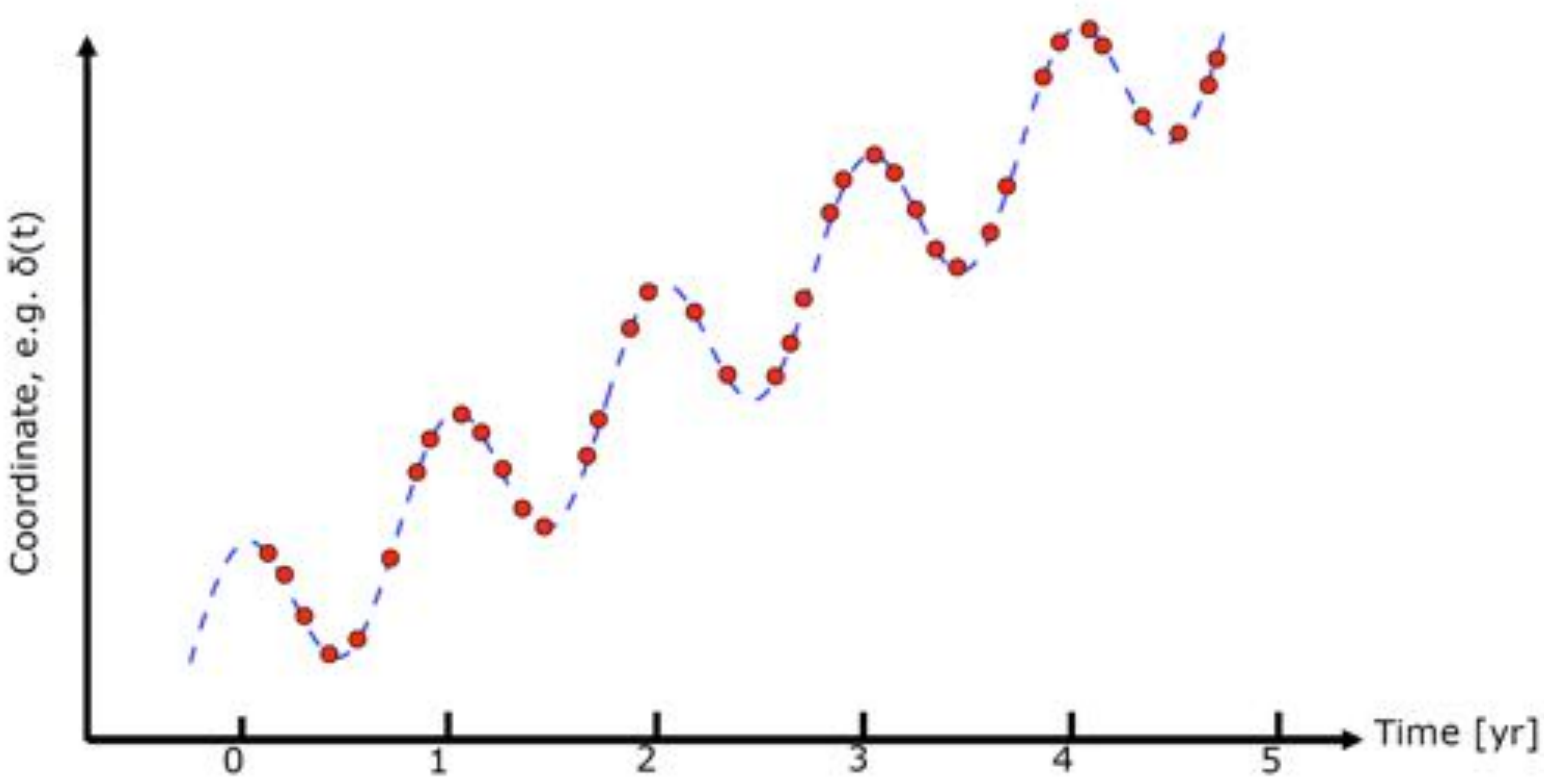
Block iterations

AGIS:Astrometric Global Iterative Solution (block-iterative least-squares Solution) of the over-determined system of equations



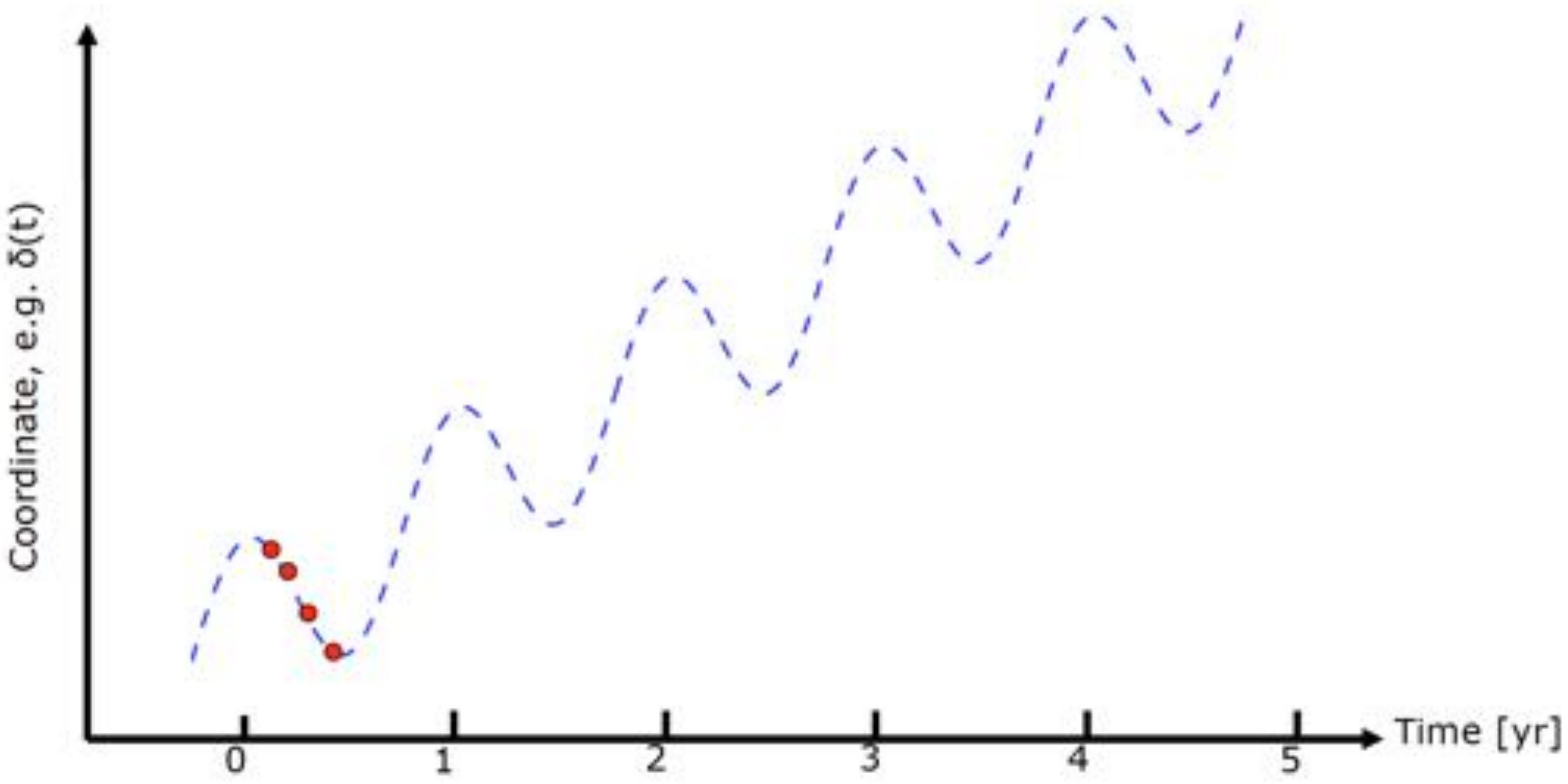
U. Lammers

Observations over 5 yr ⇒ pos, par, p.m.



from Lammers et al.

Degeneracy for less than 1 year



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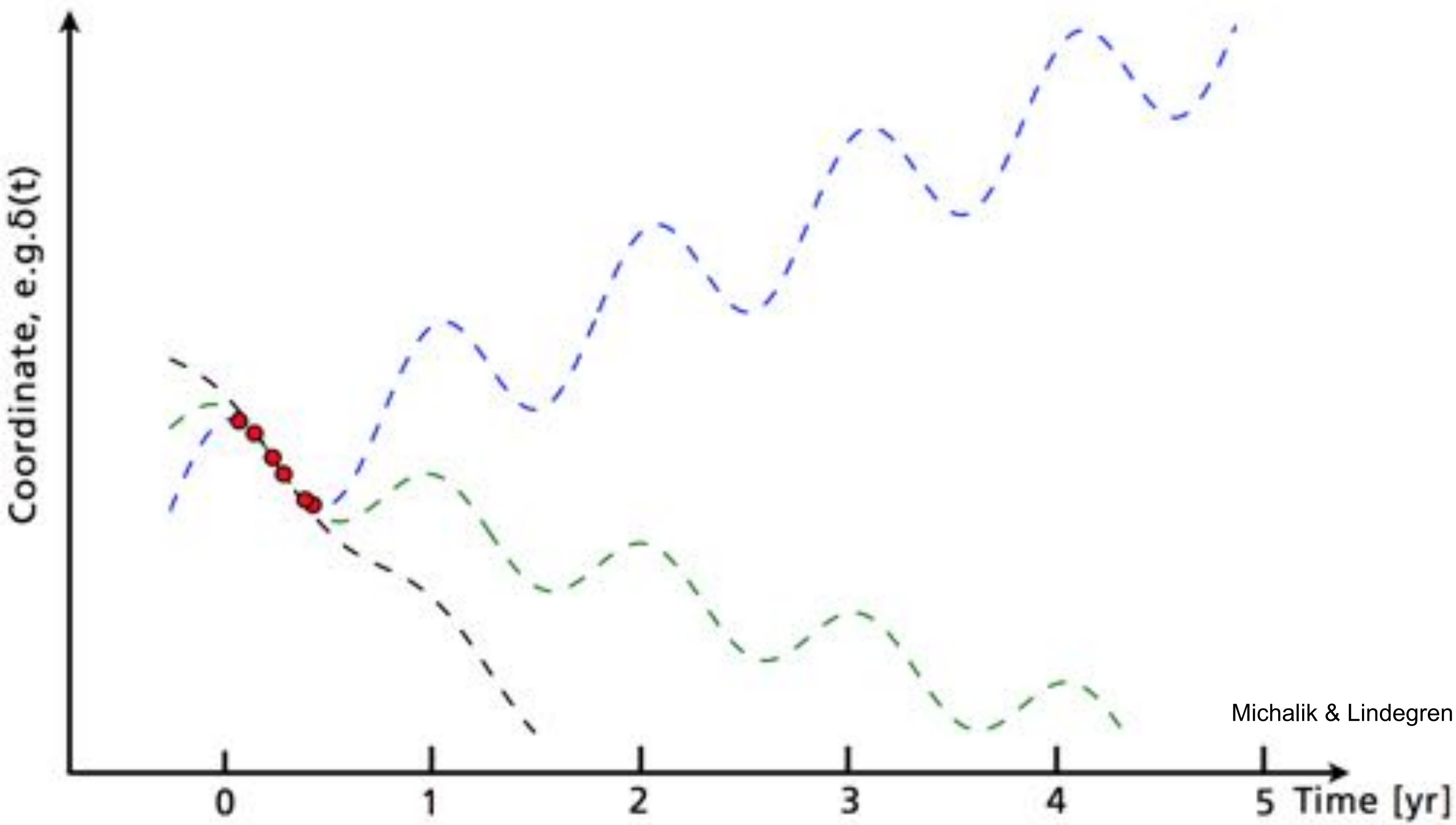
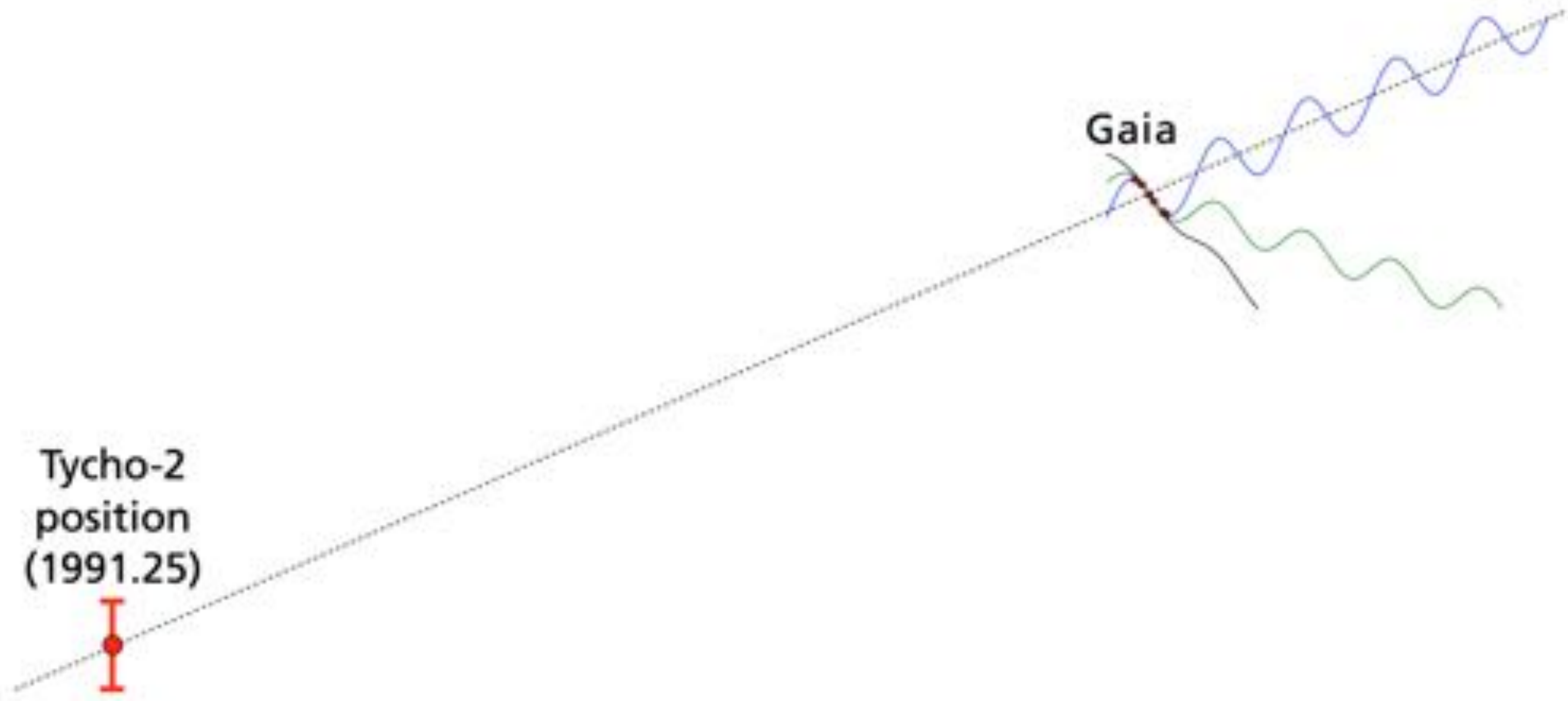


Michalik & Lindegren

Observation of less than one year plus one old position

⇒ **Independent** long-baseline proper motions, parallaxes



Michalik & Lindegren

Why use astrometric parameters?

Observations of Solar System can be modelled directly

in barycentric coordinates r (t)

For stars and more distant objects the astrometric parameters are preferred:

- they can always be fitted to astrometric observations
- resulting errors are approximately Gaussian
- they work even for sources at “infinite” distance

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Example:

Astrometric parameters in Gaia DR1 for the quasar 3C273 (HIP 60936):

t_{ep} = 2015.0 (chosen)

α = 187.277915798° ± 0.312 mas* $\quad$ $\mu_{\alpha*}$ = −0.384 ± 0.443 mas/yr

δ = +2.052388638° ± 0.216 mas $\quad$ μ_{δ} = +0.111 ± 0.288 mas/yr

ϖ = −0.140 ± 0.377 mas $\quad$ v_r = 0 (assumed)

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Three remarks on the astrometric parameters

The sixth parameter, radial velocity v_r (or radial proper motion $\mu_r = \varpi v_r / A$), is ignored in Gaia DR1 (assumed = 0)

- important for a small number of nearby, high-velocity stars (not in DR1 anyway)
- gives a quadratic variation of position (perspective acceleration)

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The astrometric parameters describe the instantaneous motion at the specified reference epoch t_{ep} (= 2015.0 for Gaia DR1)

- especially the position parameters (α, δ) depend on t_{ep} due to proper motion
- the parameters can be transformed to any desired epoch (see documentation)
- future releases will use a different reference epoch than 2015.0
- “epoch” not to be confused with “equinox” (e.g. J2000.0 = ICRS)
  the “equinox” is always the same: ICRS

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The asterisk signifies that a differential quantity in α is a "true arc":

$$\mu_{\alpha*} = \frac{d\alpha}{dt}\cos\delta\,, \quad \sigma_{\alpha*} = \sigma_\alpha \cos\delta\,, \quad \Delta\alpha* = \Delta\alpha\cos\delta$$

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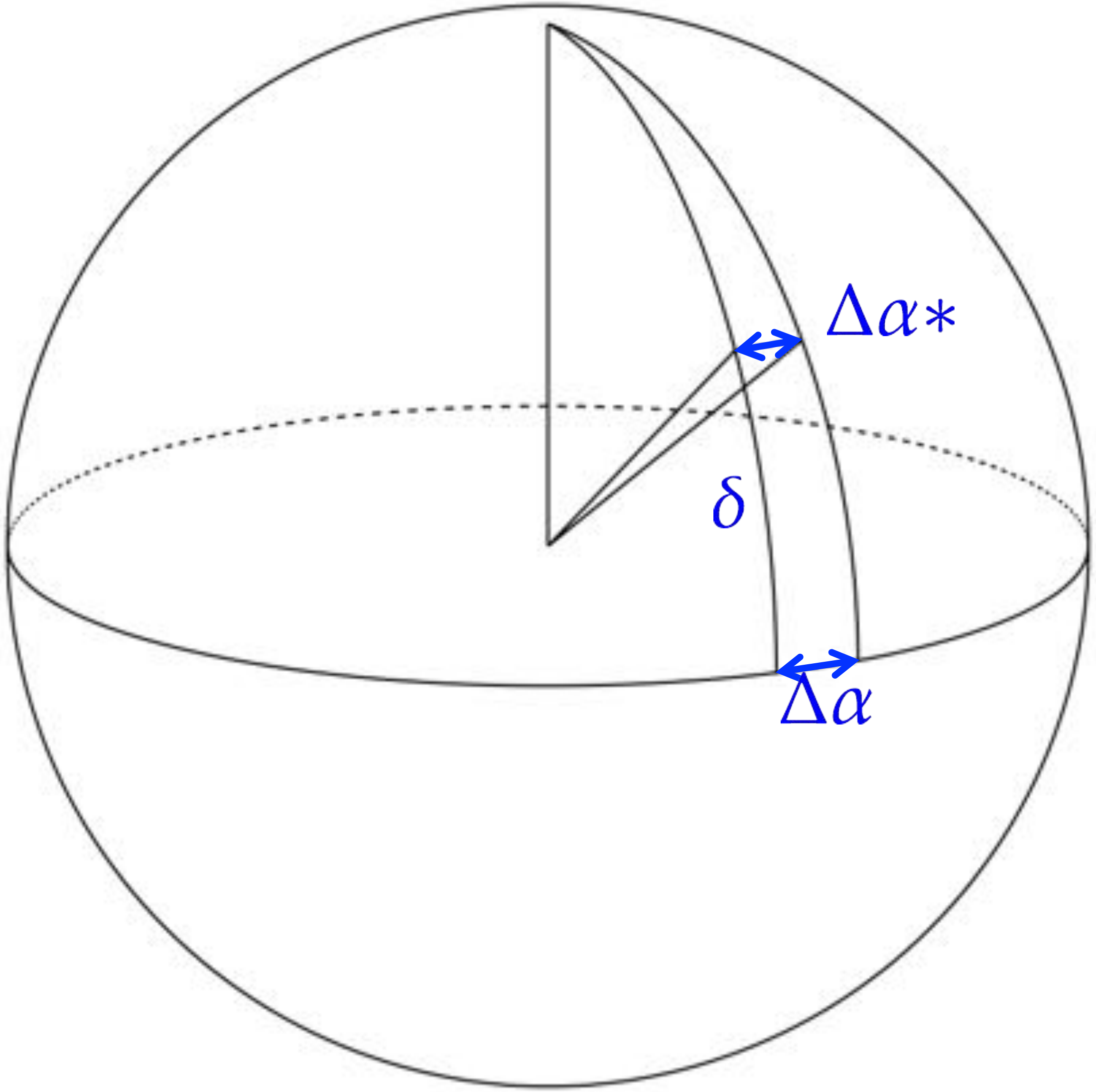
$\Delta\alpha* = \Delta\alpha \cos\delta$



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Number of sources and parameters in Gaia DR1

Solution	No. of sources	Param.	Prior used
Primary (TGAS) sources	2 057 050	5	positions at 1991.25
- of which Hipparcos	93 635	5	- Hipparcos positions
- of which Tycho-2 (excl Hipp)	1 963 415	5	- Tycho-2 positions
Secondary sources	1 140 622 719	2	ϖ, $\mu_{\alpha*}$, μ_δ = 0 ± few mas(/yr)
ICRF sources (*) = QSOs	2 191	2	$\mu_{\alpha*}$, μ_δ = 0 ± 0.01 mas/yr
All	1 142 679 880		d($\mu_{\alpha*}$, μ_δ)/dt = 0 , i.e. v_r = 0

(*) 2080 of the ICRF sources are also secondary sources (with slightly different positions)

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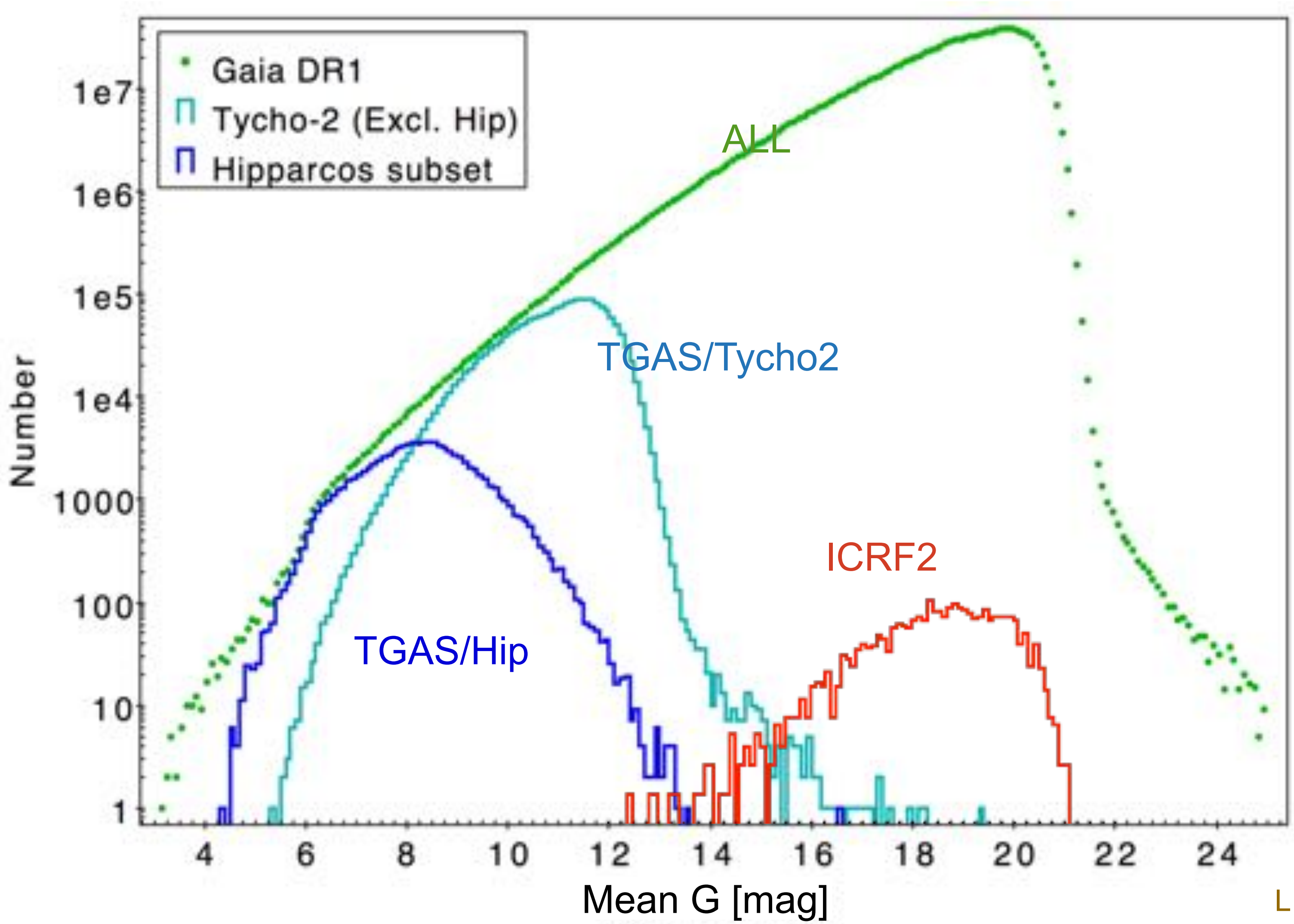
Magnitude distributions of Gaia DR1



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Primary (TGAS) sources

2.06 M sources, mainly $G < 11.5$

- this is about 80% of the Hipparcos & Tycho-2 catalogues

Missing sources:

- brights stars ($G < 6$)
- high-proper motion stars ($\mu > 3.5$ "/yr)
- some 20% of Hip + Tycho-2 with too few observations (quasi-random but with large variations over the sky)

"inflated" uncertainties; from Hipparcos comparison

Median position uncertainty: 0.23 mas at 2015.0

Median parallax uncertainty: 0.32 mas

Median proper motion uncertainty:

- 0.07 mas/yr (Hipparcos subset)
- 1.2 mas/yr (Tycho-2 subset)

Note difference!

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Astrometric quantities in Gaia DR1

- Important:
  - source_id
  - ref_epoch (always = 2015.0 in DR1)
  - ra, dec
  - ra standard error, dec standard error
  - astrometric_excess_noise

  - hip, tycho2_id
  - parallax, pmra, pmdec
  - parallax, pmra, pmdec standard errors

  } TGAS only

  - Plus number counts: n_obs, n_outliers etc.

  - Non-astrometric: G magnitudes and their uncertainty
    variable stars (Cepheids & RR Lyraes)

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Astrometric quantities in Gaia DR1

- Less important, but still very useful:
  - correlations (ra_dec_corr, etc)
  - astrometric_delta_q

HIP subset of TGAS only

- For specialists:
  - number of observations (astrometric_n_*)
  - scan_direction_strength_*, scan_direction_mean_*
  - ...

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Astrometric excess noise: Background

- The astrometric solution can be formulated as a chi-square minimisation problem

$$\arg\min\ X^2(\boldsymbol{s},\boldsymbol{a},\boldsymbol{c}) = \sum_{\text{sources } i}\ \sum_{\text{obs } j\in i} \left(\frac{R_{ij}}{\sigma_{ij}}\right)^2$$

- where s, a, c are the source, attitude, calibration parameters, R_{ij} the residuals of source i in observation j, and σ_{ij} the formal uncertainty of the observation.

- If the model is correct, we expect $X^2_{\min} \sim \chi^2_n$, so $X^2_{\min}/n \simeq 1$ where n = degrees of freedom.

- In practice the model is never correct, at least not for all sources, so
- typically we find $X^2_{\min}/n \gg 1$, too much weight are given to bad sources, and the uncertainties of s, a, c are underestimated.

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Astrometric excess noise: Definition

The problem is instead formulated as

$$\arg\min\ X^2(\boldsymbol{s},\boldsymbol{a},\boldsymbol{c}) = \sum_{\text{sources } i}\ \sum_{\text{obs } j\in i} \frac{R_{ij}^2}{\sigma_{ij}^2+\varepsilon_i^2}$$

For every source, the excess source noise ε_i is set to the smallest value for which

$$\sum_{\text{obs } j\in i} \frac{R_{ij}^2}{\sigma_{ij}^2+\varepsilon_i^2} \leq n_i$$

where n_i is the number of degrees of freedom for source i

Remarks:

- The excess noise is an angle (in mas)
- Binaries and other badly fitting sources should get large values of ε_i
- Unfortunately, attitude and instrument modelling errors also increase ε_i

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The 59 columns of the Gaia DR1 astrometric table, part 1

source_id	BIGINT	✔		Unique source identifier
ra	DOUBLE	✔	deg	Right ascension
dec	DOUBLE	✔	deg	Declination
l	DOUBLE	✔	deg	Galactic longitude
b	DOUBLE	✔	deg	Galactic latitude
ecl_lon	DOUBLE	✔	deg	Ecliptic longitude
ecl_lat	DOUBLE	✔	deg	Ecliptic latitude
parallax	DOUBLE	✔	mas	Parallax
pmra	DOUBLE	✔	mas/yr	Proper motion in right ascension direction
pmdec	DOUBLE	✔	mas/yr	Proper motion in declination direction
phot_g_mean_mag	DOUBLE	✔	mag	G-band mean magnitude
ref_epoch	DOUBLE		yr	Reference epoch
ra_error	DOUBLE		mas	Standard error of right ascension
dec_error	DOUBLE		mas	Standard error of declination
parallax_error	DOUBLE	✔	mas	Standard error of parallax
pmra_error	DOUBLE	✔	mas/yr	Standard error of proper motion in right ascension direction
pmdec_error	DOUBLE	✔	mas/yr	Standard error of proper motion in declination direction
astrometric_delta_q	REAL			Hipparcos/Gaia data discrepancy (Hipparcos subset of TGAS only)
astrometric_excess_noise	DOUBLE		mas	Excess noise of the source
astrometric_excess_noise_sig	DOUBLE			Significance of excess noise
astrometric_n_bad_obs_ac	INTEGER			Number of bad observations AC
astrometric_n_bad_obs_al	INTEGER			Number of bad observations AL
astrometric_n_good_obs_ac	INTEGER			Number of good observations AC
astrometric_n_good_obs_al	INTEGER			Number of good observations AL
astrometric_n_obs_ac	INTEGER			Total number of observations AC
astrometric_n_obs_al	INTEGER			Total number of observations AL
astrometric_primary_flag	SMALLINT			Primary or seconday
astrometric_priors_used	INTEGER			Type of prior used in the astrometric solution
astrometric_relegation_factor	REAL			Relegation factor
astrometric_weight_ac	REAL		mas^-2	Mean astrometric weight of the source
astrometric_weight_al	REAL		mas^-2	Mean astrometric weight of the source
dec_parallax_corr	REAL			Correlation between declination and parallax
dec_pmdec_corr	REAL			Correlation between declination and proper motion in declination
dec_pmra_corr	REAL			Correlation between declination and proper motion in right ascen...

The 59 columns of the Gaia DR1 astrometric table, part 2

duplicated_source	SMALLINT			Source with duplicate sources
hip	INTEGER			Hipparcos identifier
matched_observations	SMALLINT			Amount of observations matched to this source
parallax_pmdec_corr	REAL			Correlation between parallax and proper motion in declination
parallax_pmra_corr	REAL			Correlation between parallax and proper motion in right ascension
phot_g_mean_flux	DOUBLE		e-/s	G-band mean flux
phot_g_mean_flux_error	DOUBLE		e-/s	Error on G-band mean flux
phot_g_n_obs	INTEGER			Number of observations contributing to G photometry
phot_variable_flag	VARCHAR			Photometric variability flag
pmra_pmdec_corr	REAL			Correlation between proper motion in right ascension and proper
ra_dec_corr	REAL			Correlation between right ascension and declination
random_index	BIGINT	✓		Random index used to select subsets
ra_parallax_corr	REAL			Correlation between right ascension and parallax
ra_pmdec_corr	REAL			Correlation between right ascension and proper motion in declin
ra_pmra_corr	REAL			Correlation between right ascension and proper motion in right a
scan_direction_mean_k1	REAL		deg	Mean position angle of scan directions across the source
scan_direction_mean_k2	REAL		deg	Mean position angle of scan directions across the source
scan_direction_mean_k3	REAL		deg	Mean position angle of scan directions across the source
scan_direction_mean_k4	REAL		deg	Mean position angle of scan directions across the source
scan_direction_strength_k1	REAL			Degree of concentration of scan directions across the source
scan_direction_strength_k2	REAL			Degree of concentration of scan directions across the source
scan_direction_strength_k3	REAL			Degree of concentration of scan directions across the source
scan_direction_strength_k4	REAL			Degree of concentration of scan directions across the source
solution_id	BIGINT			Solution Identifier
tycho2_id	VARCHAR			Tycho 2 identifier

More detailed descriptions in:
https://gaia.esac.esa.int/documentation/GDR1/datamodel/Ch1/tgas_source.html

Systematic errors (bias) in Gaia DR1

- There are systematic errors in Gaia DR1!
- They are complicated (and largely unknown) functions of many things:
  - position, magnitude, colour, number of observations, prior used, ...

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Systematics in Gaia DR1 parallaxes

- Due to known limitations in the astrometric processing
  - - a global offset of ±0.1 mas may be present
  - - there are colour dependent, spatially correlated errors of ±0.2 mas
  - - over large spatial scales, parallax zero point errors reach ±0.3 mas
  - - in a few very small areas even ±1 mas (is indicated)

- Parallax uncertainties in restricted areas of the sky should be quoted as
- $\varpi \pm \sigma_{\varpi}$ (random) ± 0.3 mas (syst.)
- Averaging parallaxes e.g. in a cluster does not reduce the systematics!

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What can be expected from Gaia DR2?

- Will be completely independent of Hipparcos/Tycho-2
- Based on a longer stretch of data (22 versus 14 months)
- Improved attitude and instrument models will reduce the modelling errors and hence both random and systematic errors in results
- Parallax accuracies of about 50 µas can be reached for sources down to G ~ 15 mag, larger errors for fainter sources
- Proper motions of about 100 µas yr^{-1} (comparable to the Hipparcos subset of TGAS) down to G ~ 15 mag
- This will be obtained for many tens of millions of sources
- Improved and more photometry (G, BP, RP) will enhance the scientific usefulness enormously
- Gaia DR1 is a good training set to get prepared for the real thing!

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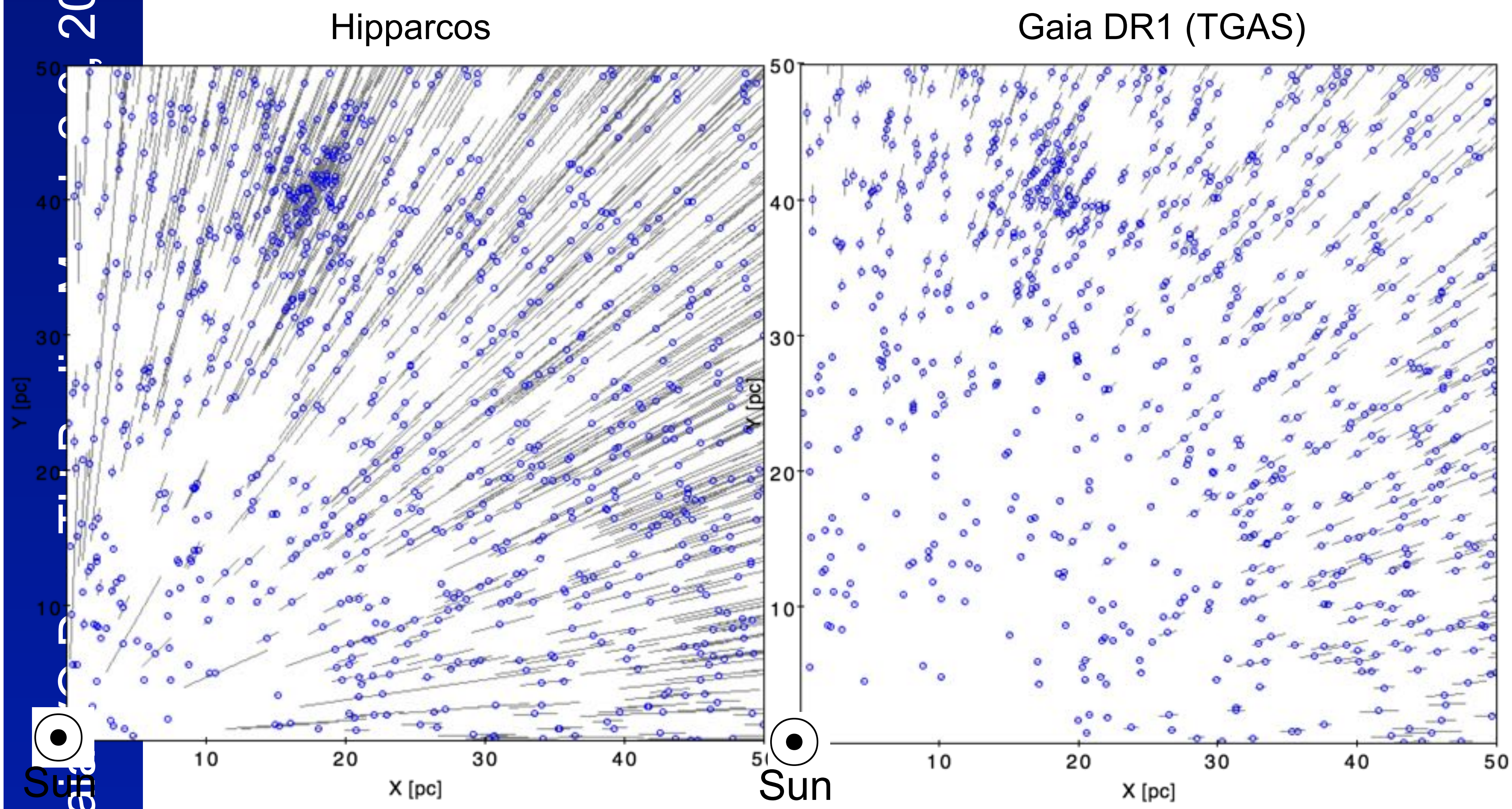
Improved distances to nearby stars



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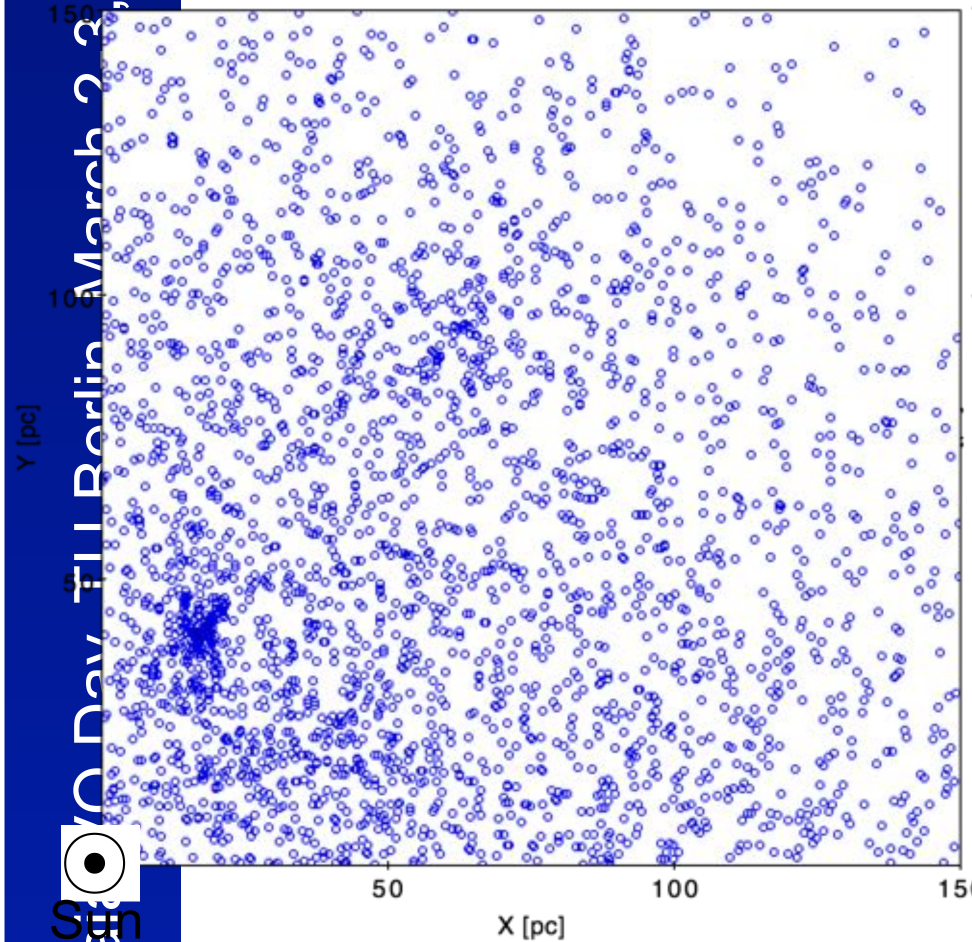
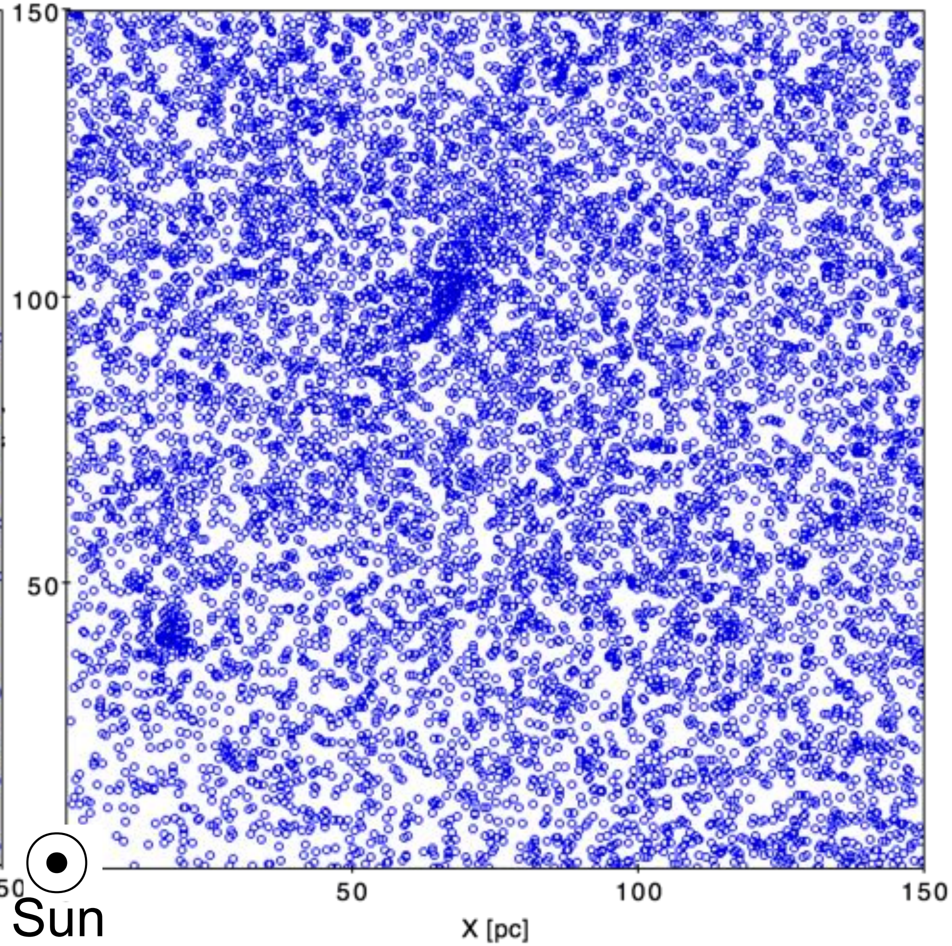
More stars within parallax horizon ($\varpi/\sigma_\varpi > 5$)

Hipparcos



Sun

Gaia DR1 (TGAS)



Sun

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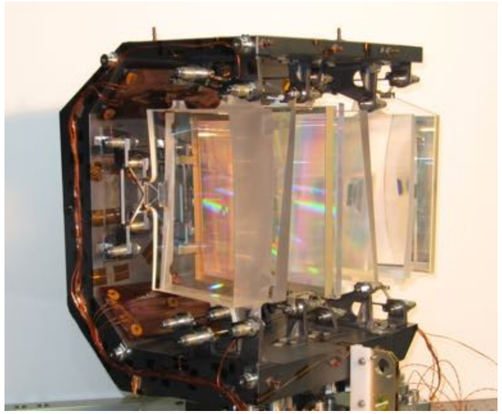
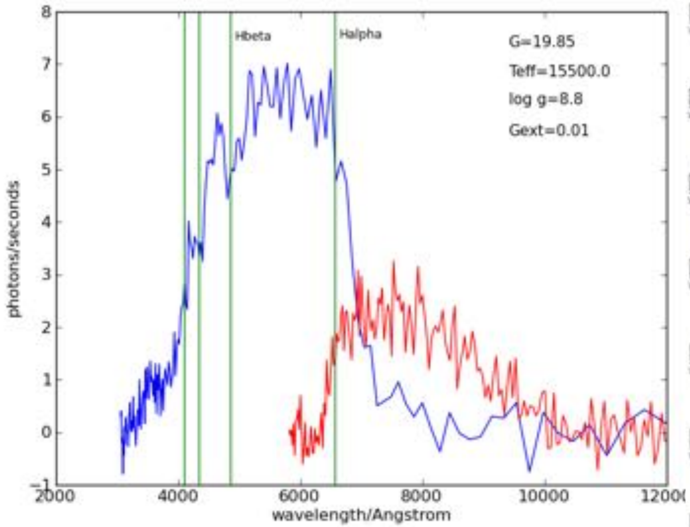
Status of measurements

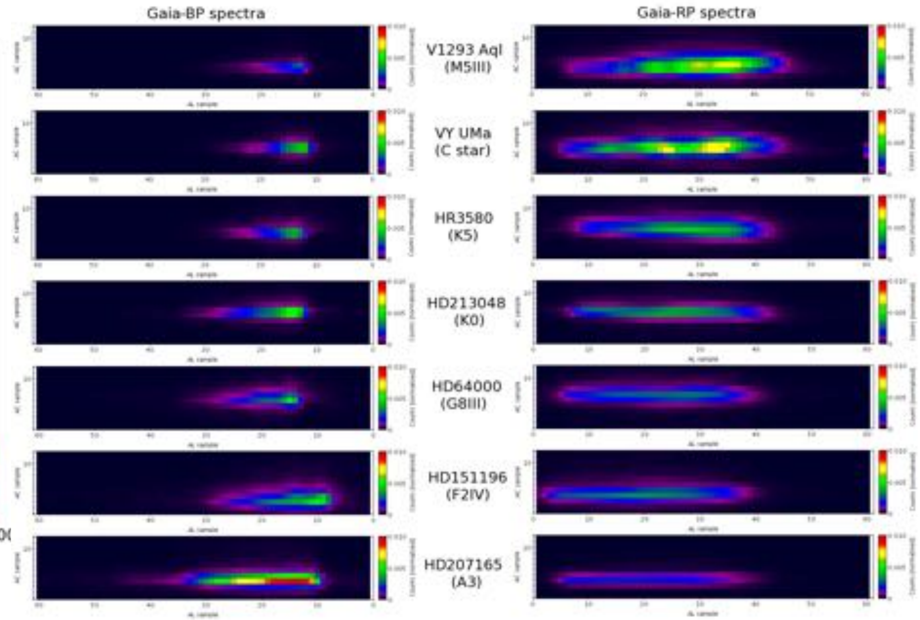
- **Astrometric measurements**: 556 billion
- G<20.7 mag
- Bright limit around G=2-3 mag
- All bright stars imaged (G<3 mag) (Gaia SM)
- **Photometric measurements**: 120 billion
  - 330-680 nm BP
  - 640-1050 nm RP
- Photometry in G-band on astrometric detectors
- **Spectroscopic measurements**: 11 billion
- G_{RVS}<16.2 mag
  - 845-872 nm with R about 11,000
- Radial Velocity Spectrometer for >100 million radial velocities
- Bright limit around G=2-3 mag

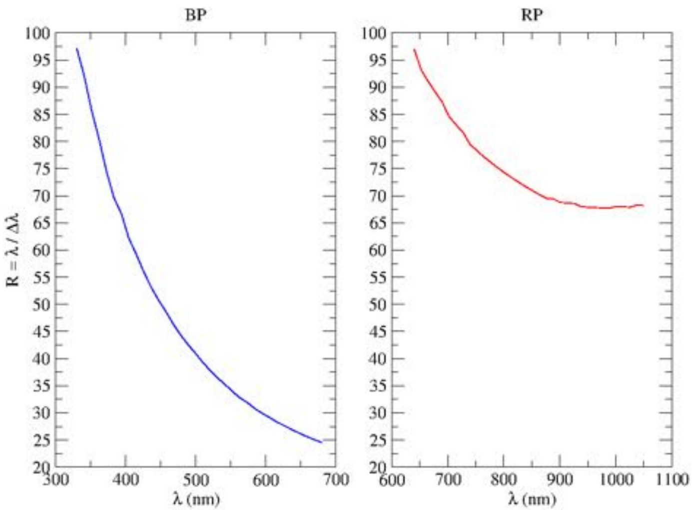


RVS spectrograph

Blue and Red Photometer

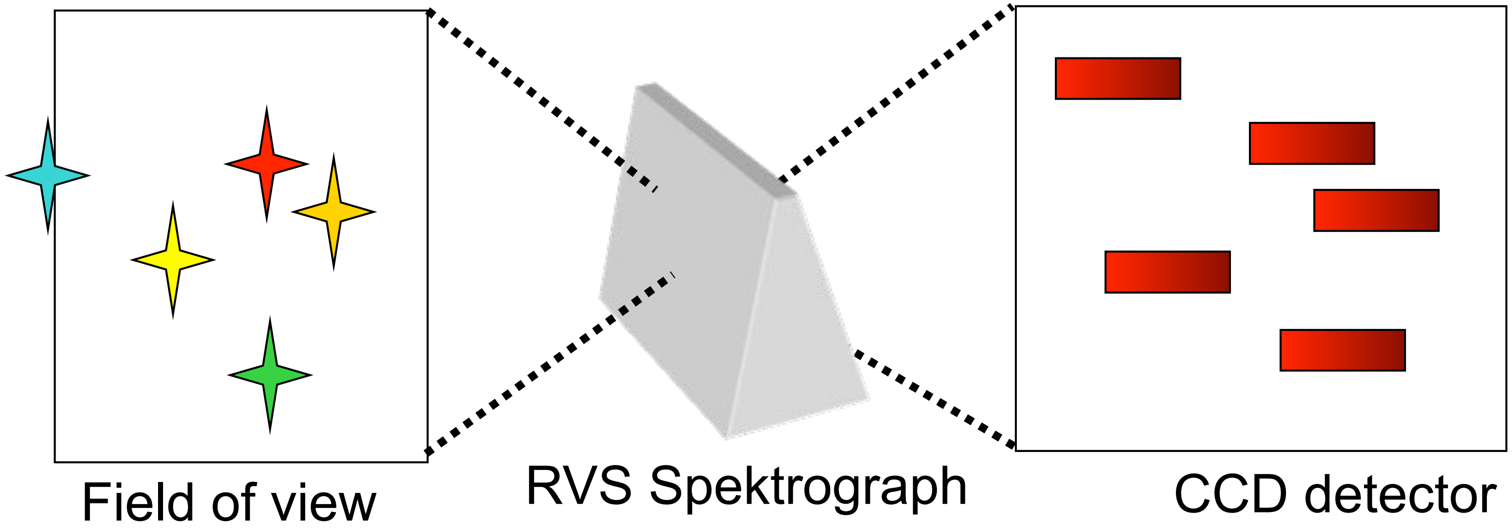


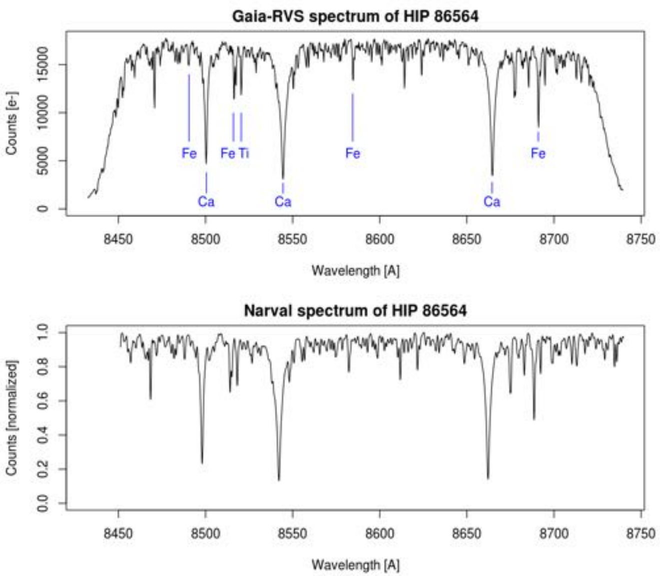




Δλ/λ<100

Radial-velocity Spectrograph

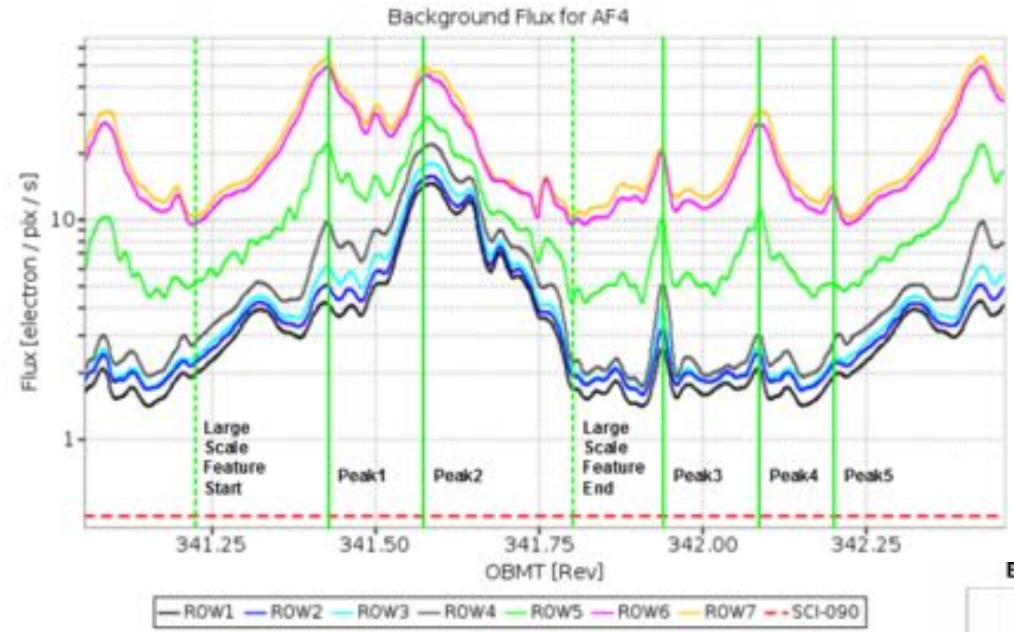


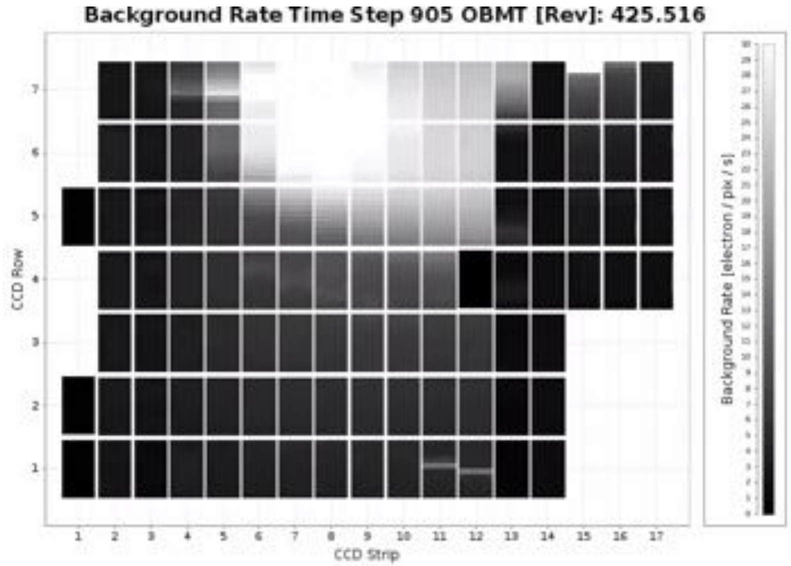


Single RVS spectrum of K5 star HIP 86563 (V=6.63) compared to a ground-based spectrum

$\Delta\lambda/\lambda=11500$

Excessive Straylight

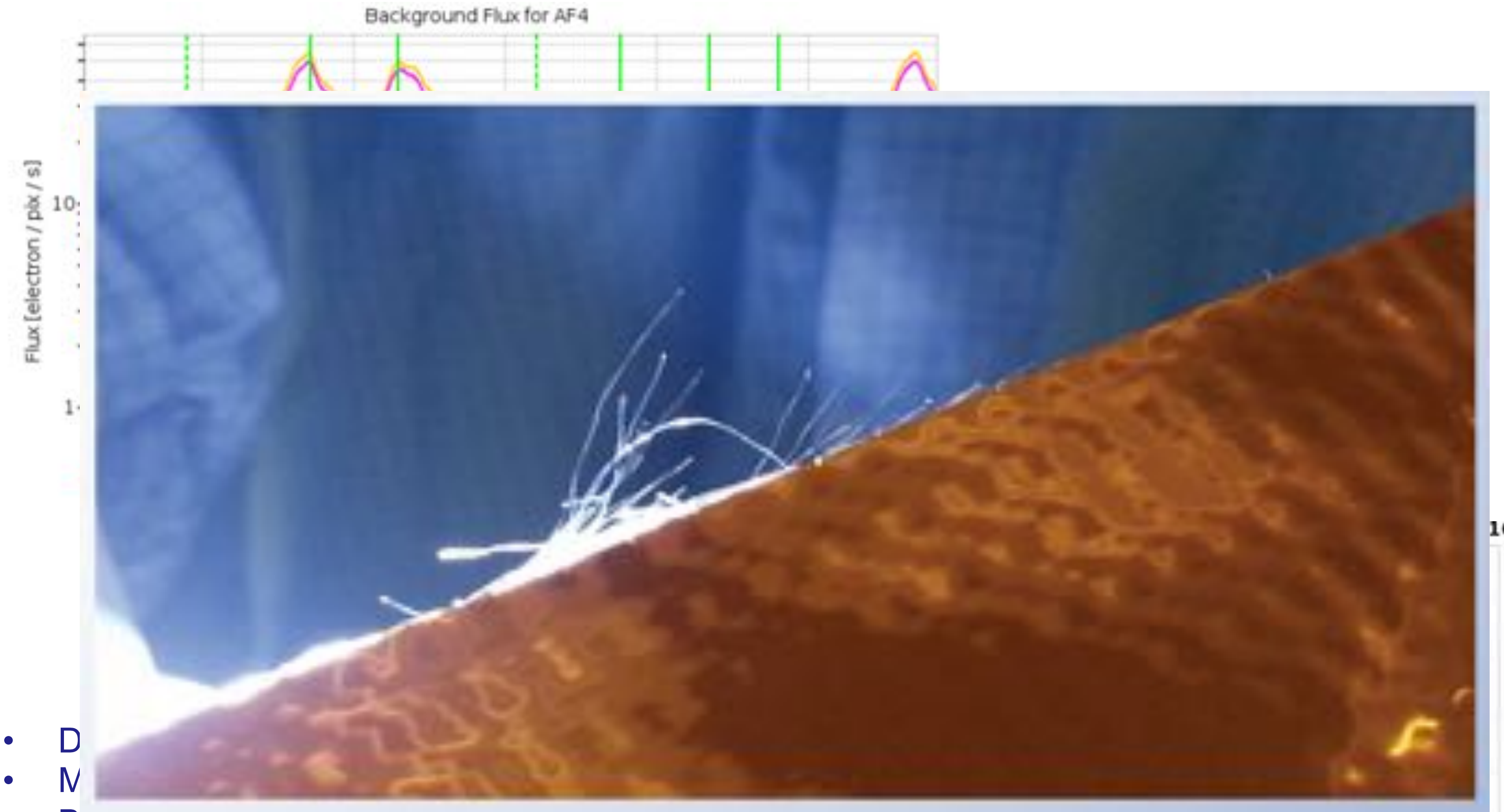


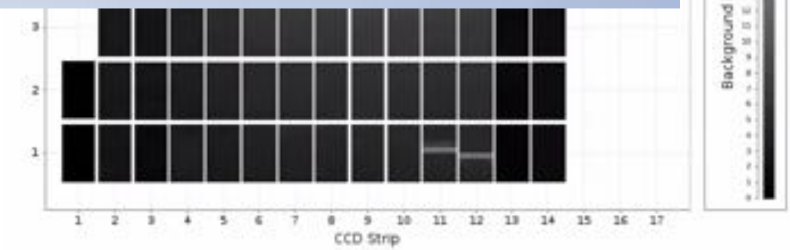


- Diffracted sunlight
- Milky Way
- Bright point objects

1. Sunshield
2. Insufficient baffling

Excessive Straylight

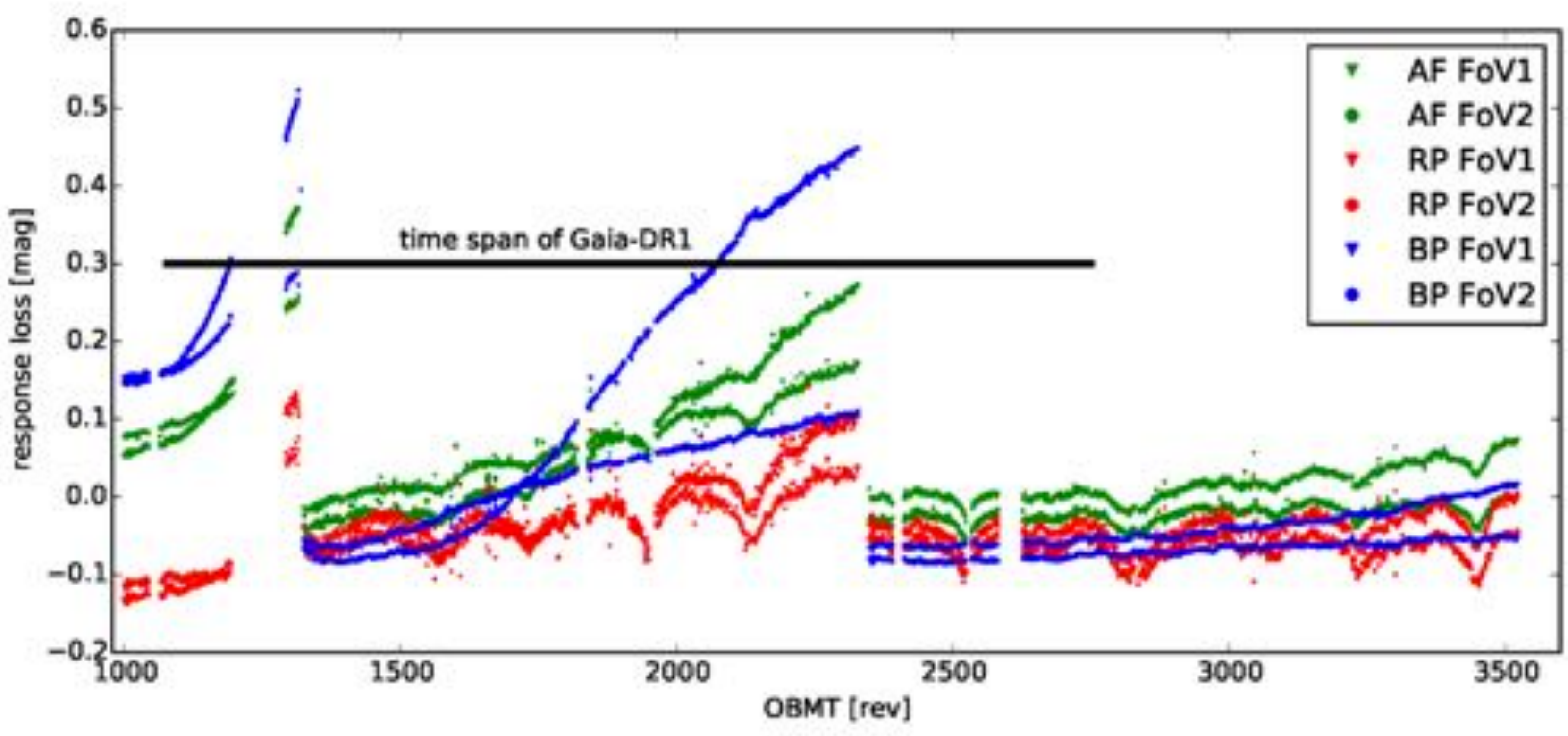




- D
- M
- Bright point objects

1. Sunshield
2. Insufficient baffling

Contamination



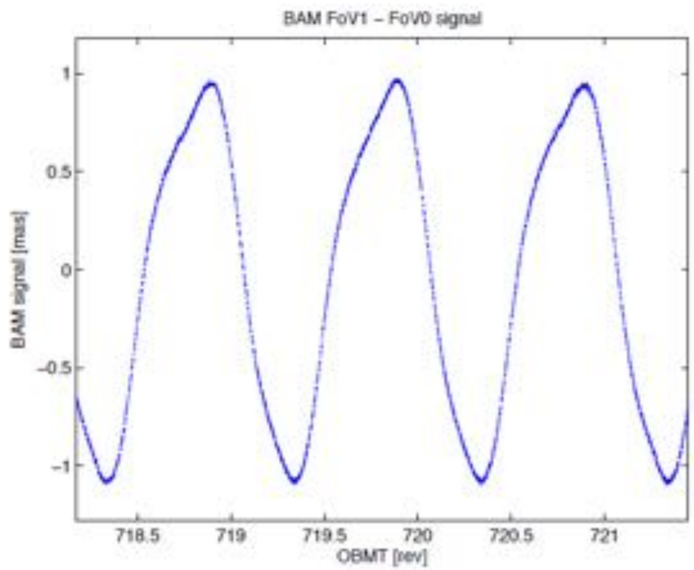
CU5/DPCI team

Cyclic Variation of the Basic Angle

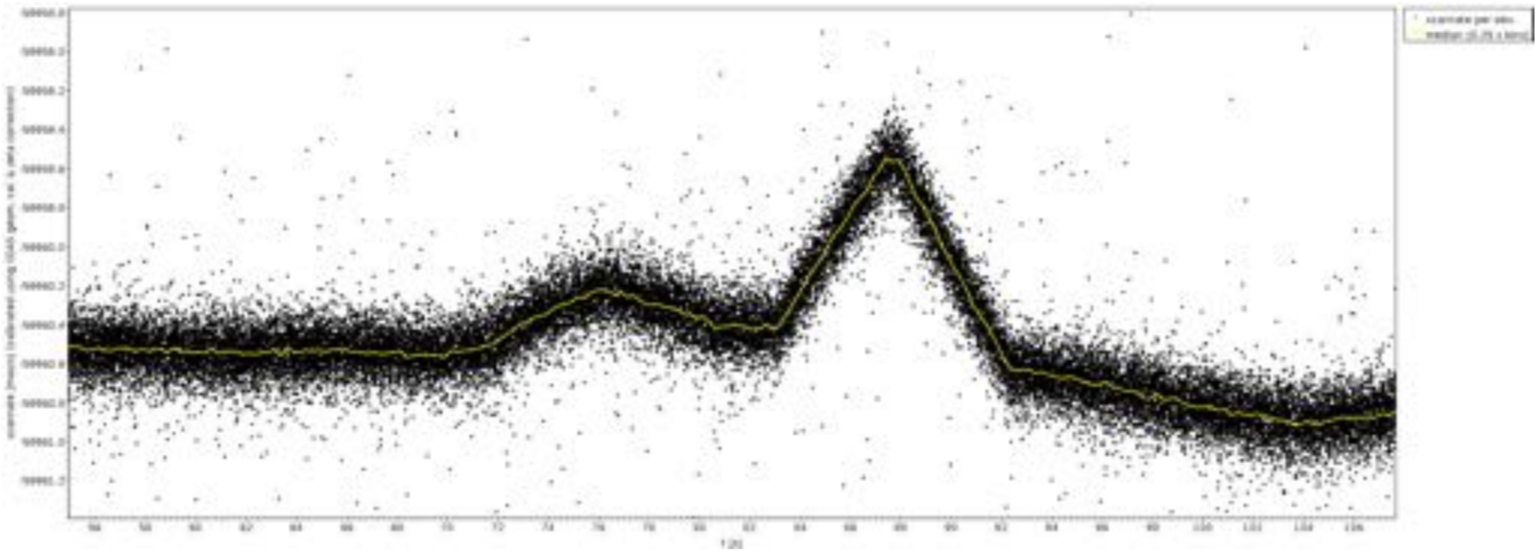
- The basic angle varies with a period of 6 hours=rotation with respect to the Sun
- Amplitude: 1.1 milliarcseconds
- Specification: 4 microarcseconds
- Corresponds to a shift of only a few nanometers

1 mas = $5 \cdot 10^{-9}$ 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!



Apparent scan rate variations

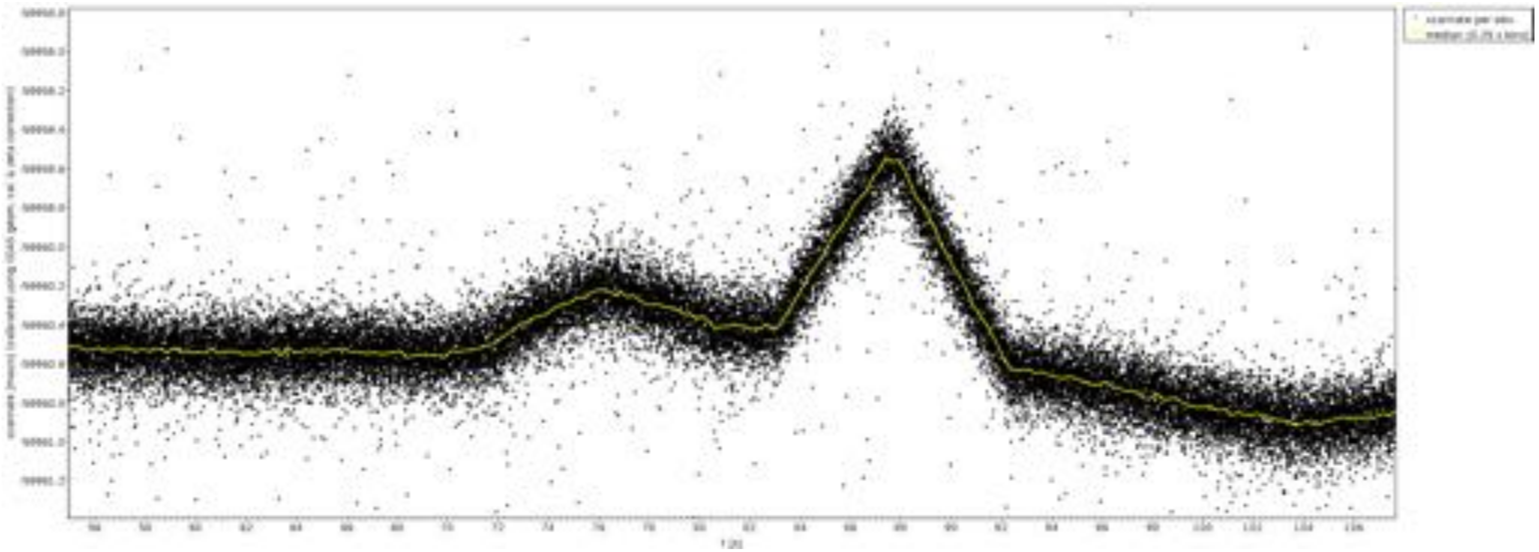


Shape of the wiggles: => clanks! The big one is 4.7 mas = 35 nm at 1.5m

Micro-clank hypothesis confirmed !

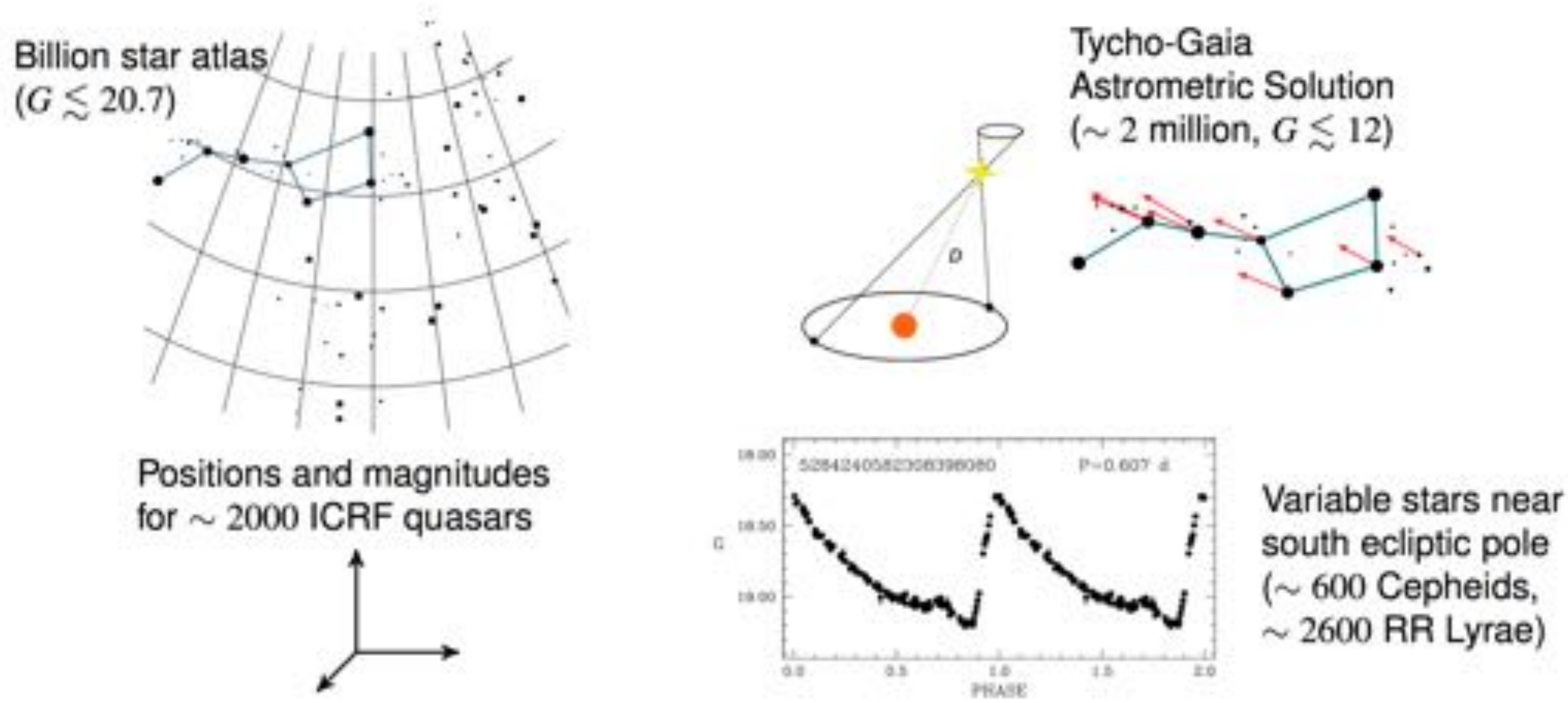
There are 2 clanks in fact: The size of the big one is 4.7 mas = 0.97 mas/s * 4.86 s ; the size of the small one is 1.3 mas = 0.26 mas/s * 4.86s

Apparent scan rate variations



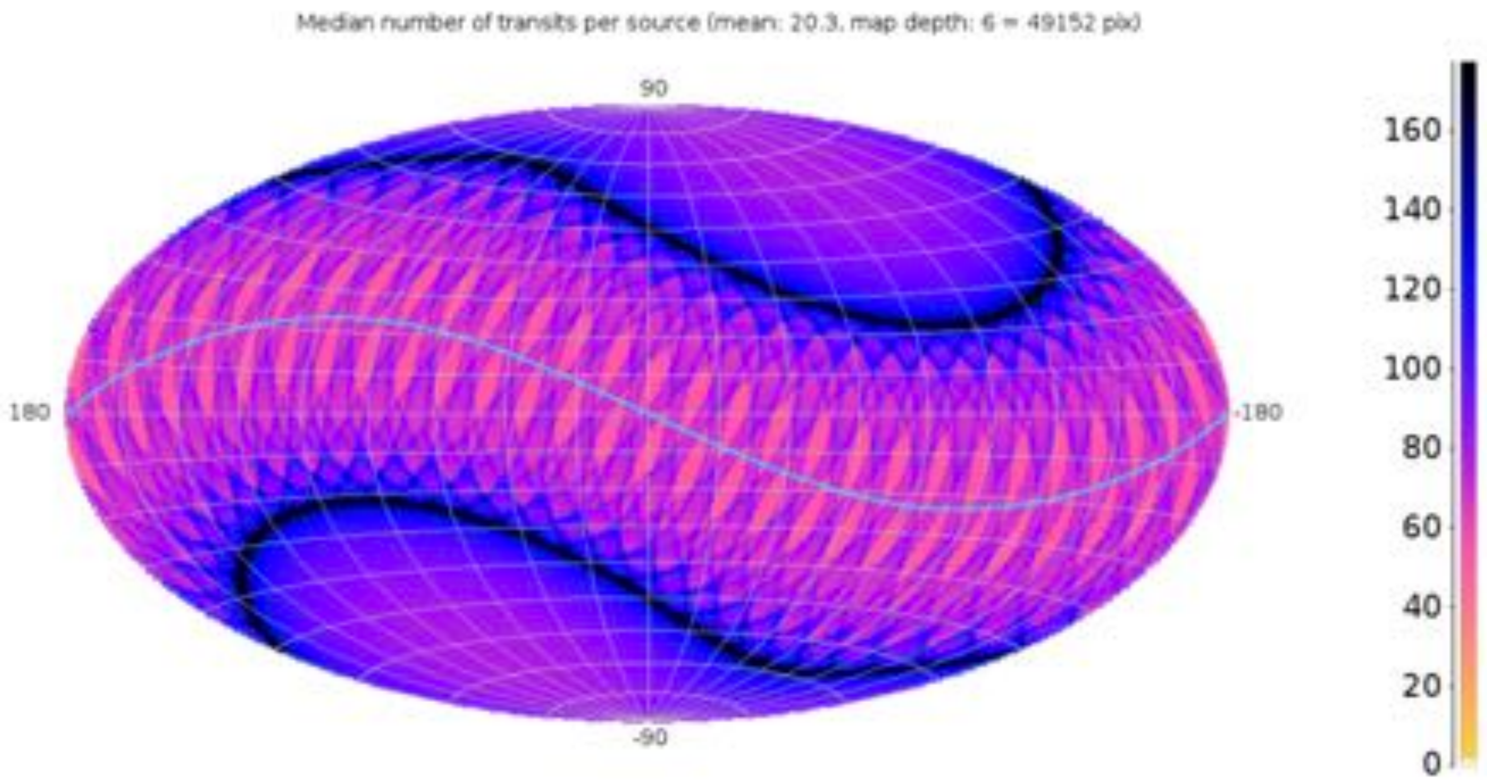
Micro-clanks!

Gaia DR1 content (Sep 14, 2016)



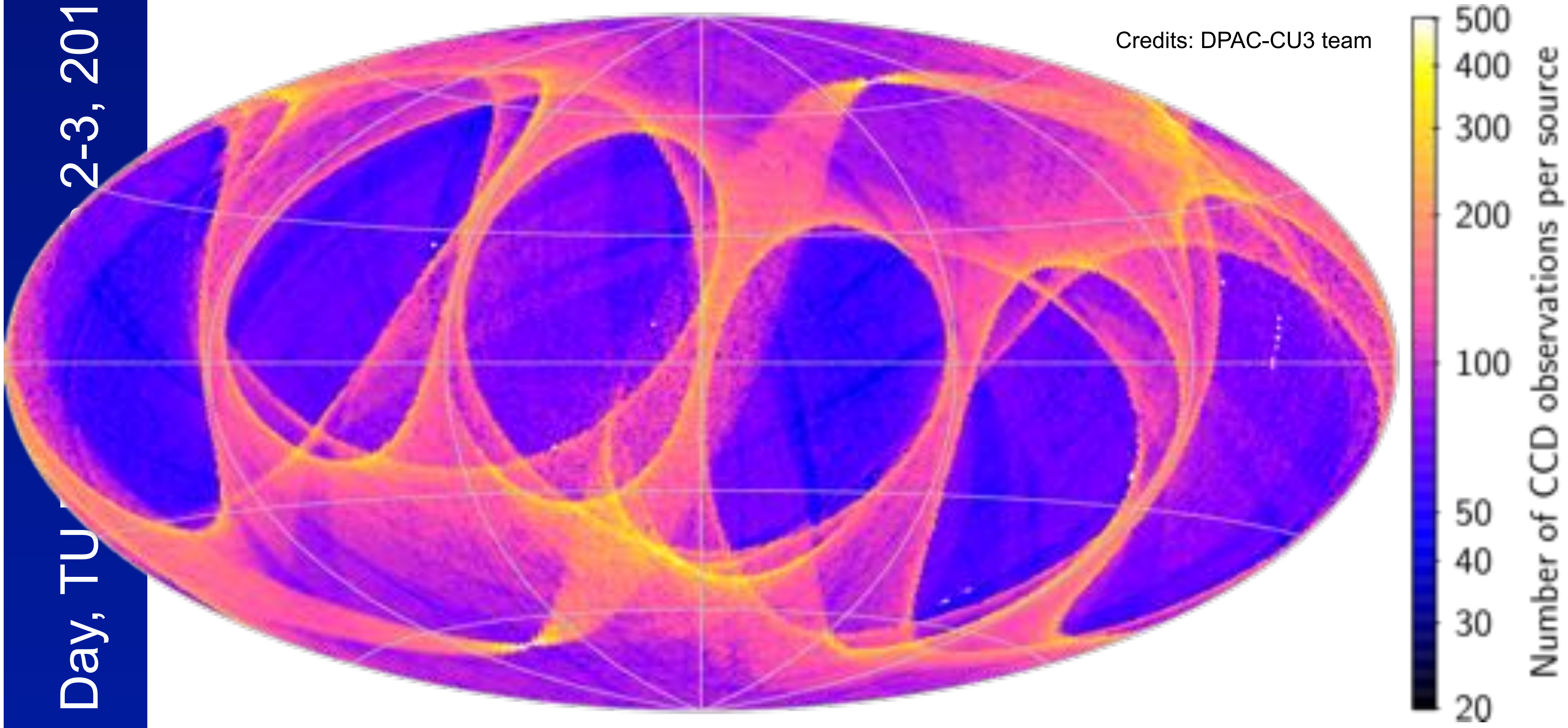
A. Brown

Gaia observations in 5 years



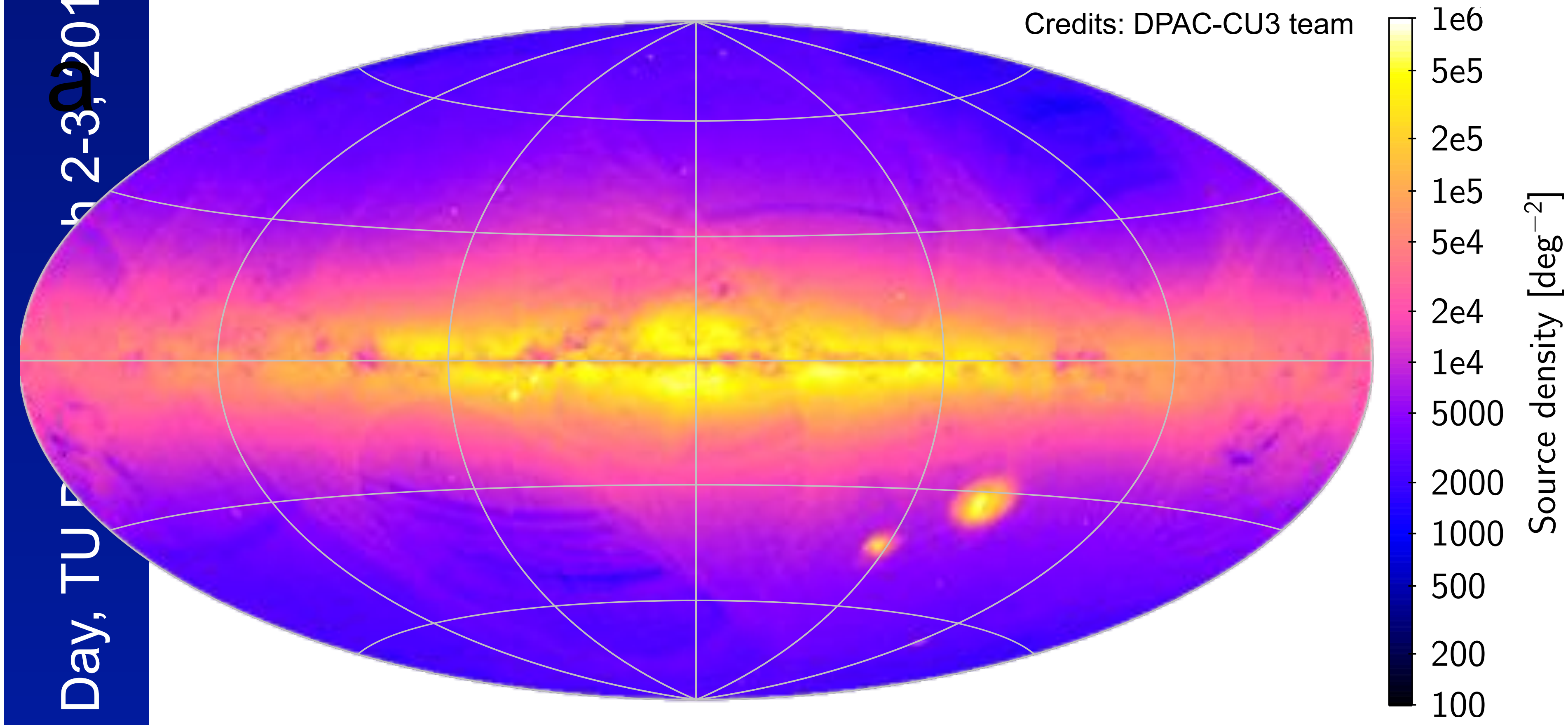
Number of transits in a nominal 5 year interval: smooth coverage, 80 transits on average

Gaia DR1- Mean no. observations per pixel (~ 1 deg²)



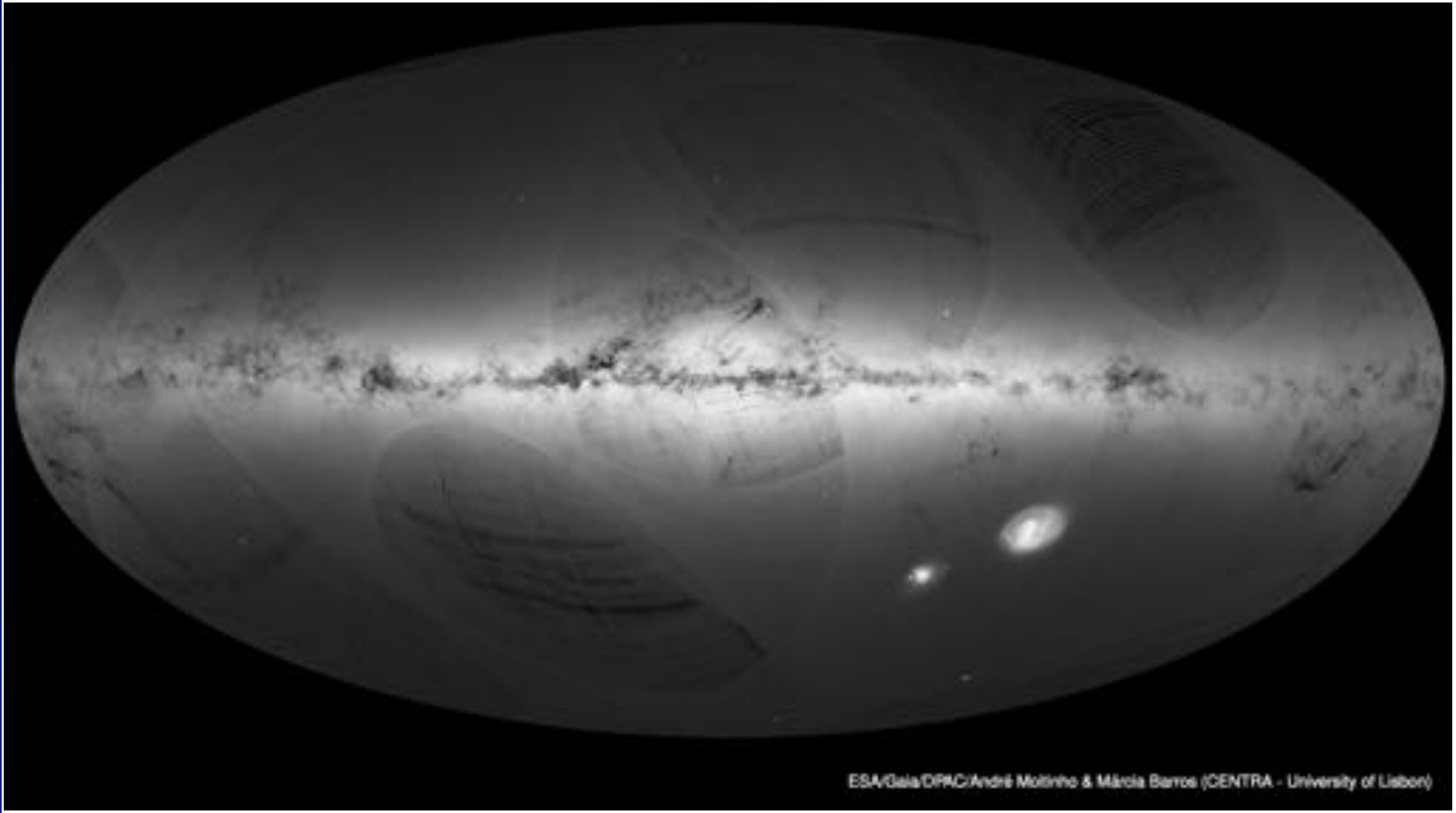
- 14 (effectively 11) months of input data
- ~ 2.3×10^{10} transits across focal plane
- Only single star solutions

DR1 – Source density per sq. degree



- (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}

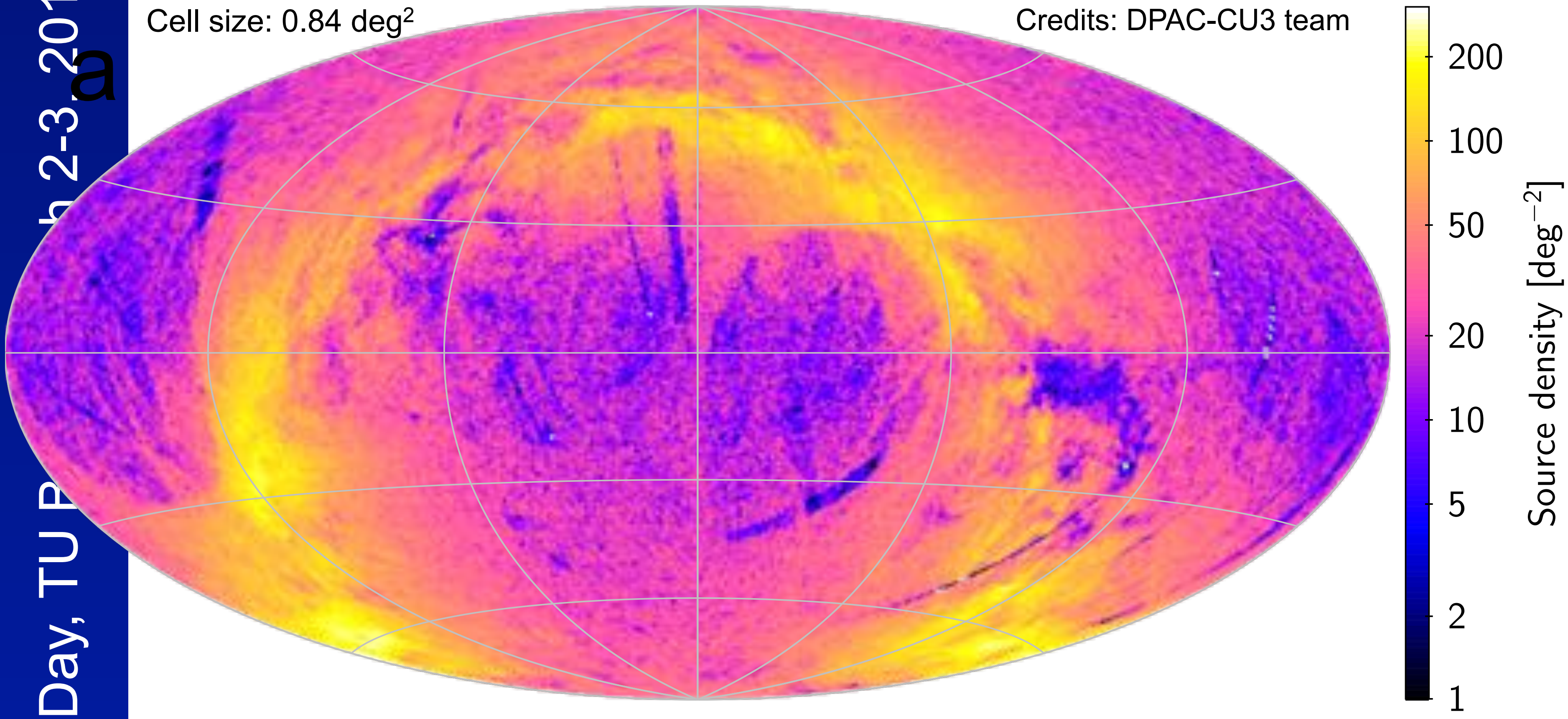
Source density map of Gaia DR1



TGAS

- Tycho-Gaia: long-baseline astrometry, full five parameter
- Preliminary results (real data!) very exciting and promising
  • 2057050 parallaxes and proper motions, Hipparcos-like quality, often better, for stars with G<11.5
- 1 million of very high quality ($\sigma_\pi \approx 0.3$ mas)
- Independent parallaxes and proper motions, incl. Hipparcos stars
- Long-period exoplanets from $\Delta\mu=\mu_{TGAS}-\mu_{Hipparcos}$
  Challenges: scientific validation, basic angle variations
- Quality of parallaxes verified through quasars

DR1- TGAS Source density

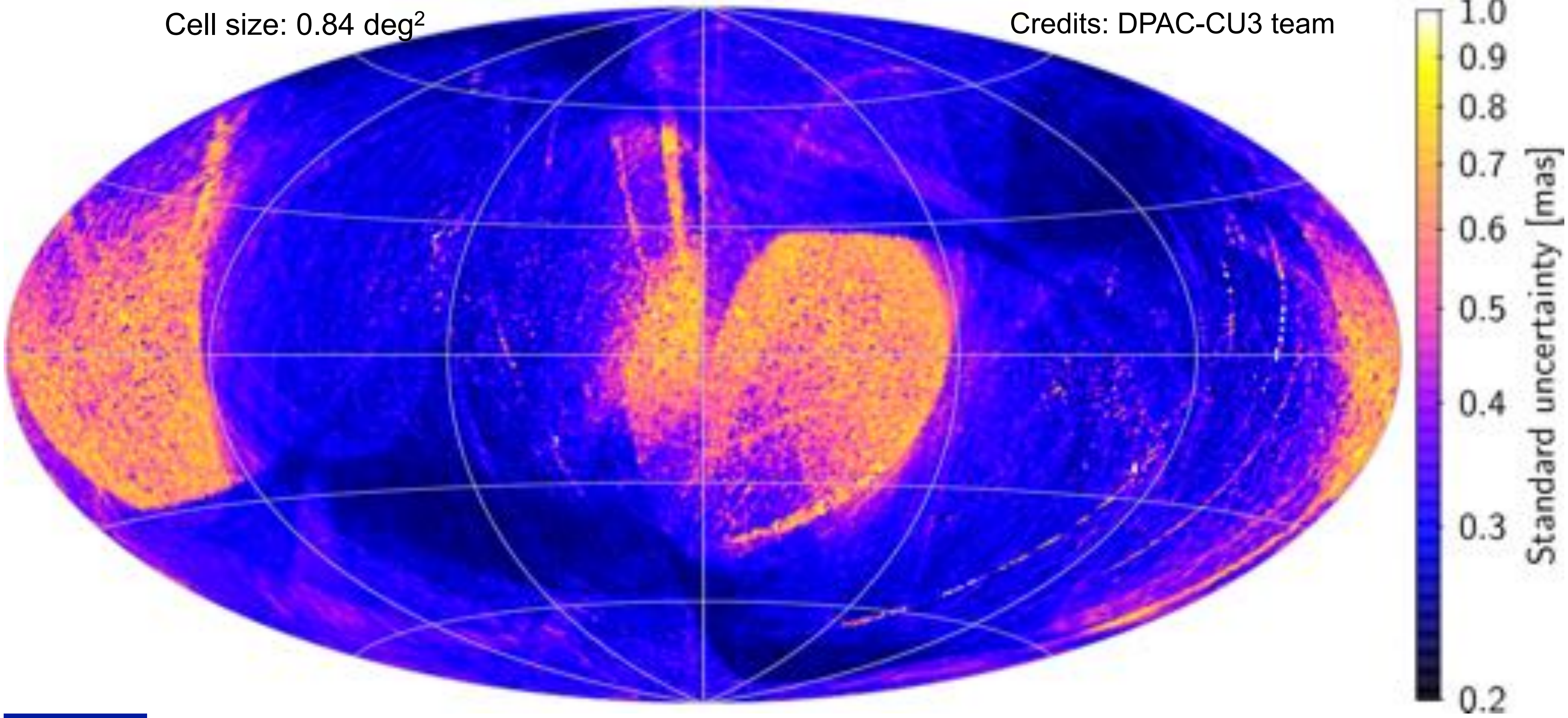


- Parallaxes and proper motions for ~ 2 million TGAS sources
- Realistic errors derived from Gaia-Hipparcos comparison
- Median positional uncertainty ~ 0.3 mas

DR1- Parallax uncertainty

Cell size: 0.84 deg^2

Credits: DPAC-CU3 team

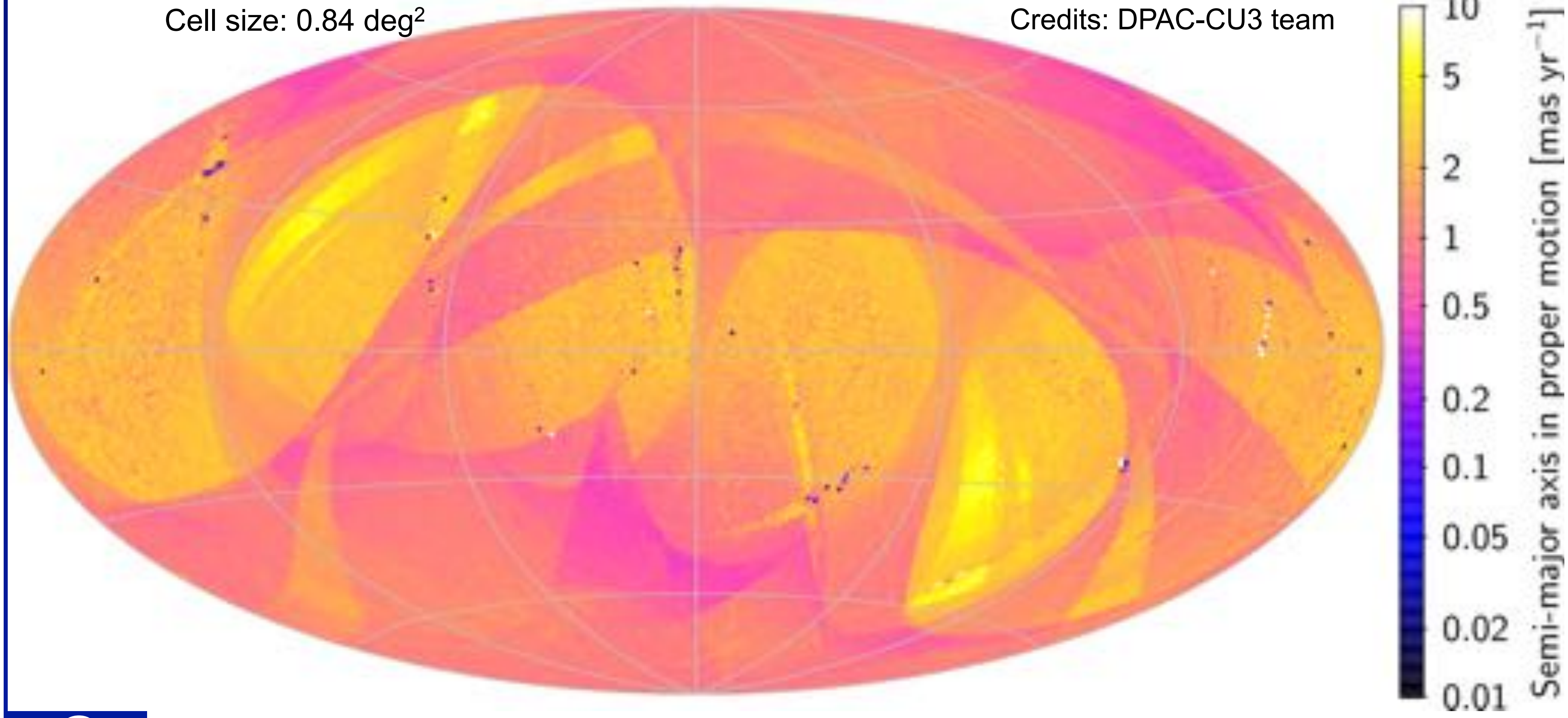


- Median parallax uncertainty ~ 0.3 mas
- Parallax systematics at 0.3 mas level
- Errors levels partly reflect early scanning law coverage and geometry

DR1- TGAS median proper motion uncertainty

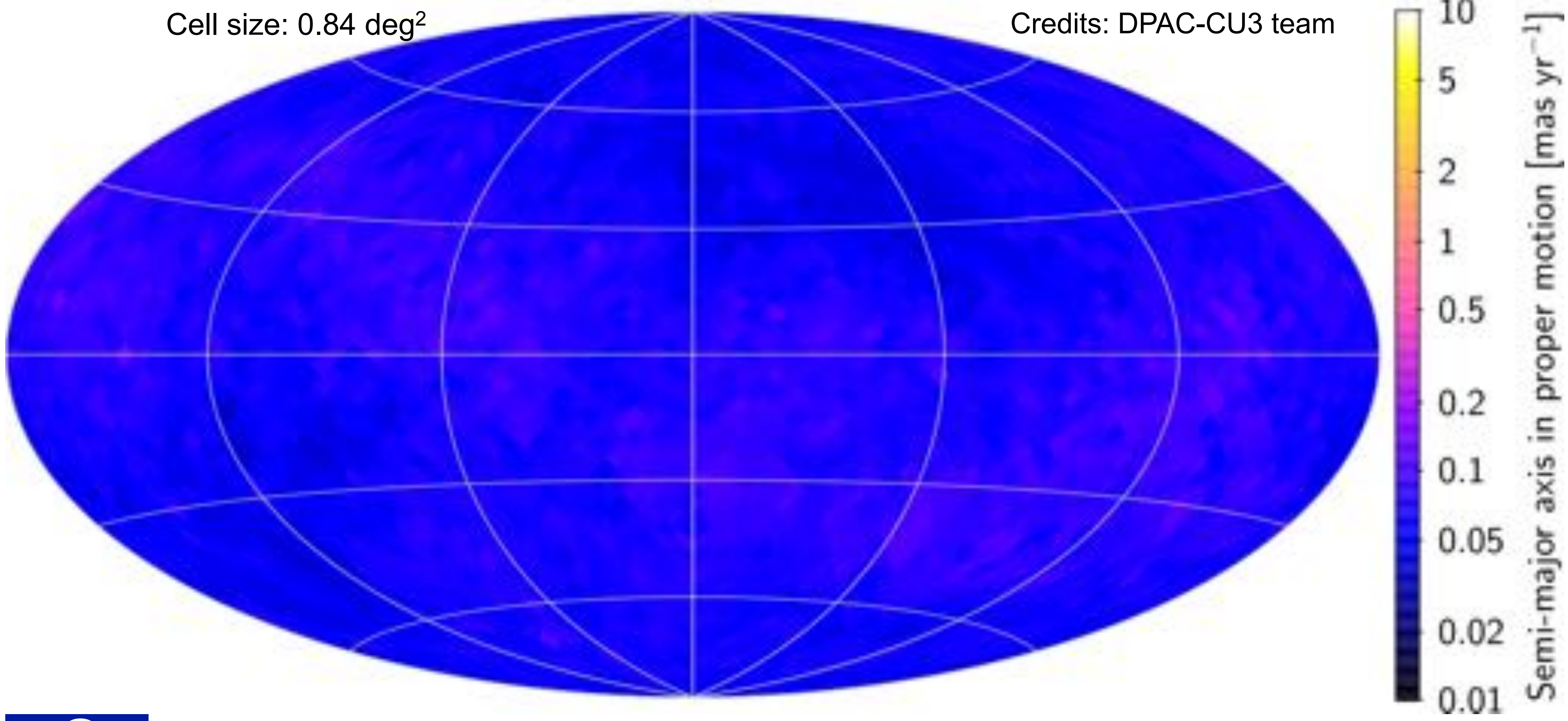
Cell size: 0.84 deg^2

Credits: DPAC-CU3 team



- Median proper motion uncertainty ≈ 1.3 mas yr^{-1}
- Also about 0.3 mas yr^{-1} systematic error!

DR1- TGAS (Hipparcos subset) median proper motion uncertainty



- Median proper motion uncertainty ≈ 0.07 mas yr^{-1}
- <0.1 mas yr^{-1} systematic error!

DR1- TGAS – astrometric uncertainties

	All primary sources (2 087 000 stars)			**Hipparcos subset** (101 000 stars)		
	10 %	**50 %**	**90 %**	**10 %**	**50 %**	**90 %**
G magnitude	9.29	11.04	12.05	7.00	8.32	9.73
position (mas)	0.20	0.32	0.75	0.20	0.26	0.46
parallax (mas)	0.24	0.32	0.64	0.23	0.28	0.48
proper motion (mas/yr)	0.72	1.32	3.19	0.04	0.07	0.14

- These are *precisions*. There is an additional systematic error of 0.3 mas (mas/yr)
- Systematic error of Hipparcos proper motions <0.1 mas)

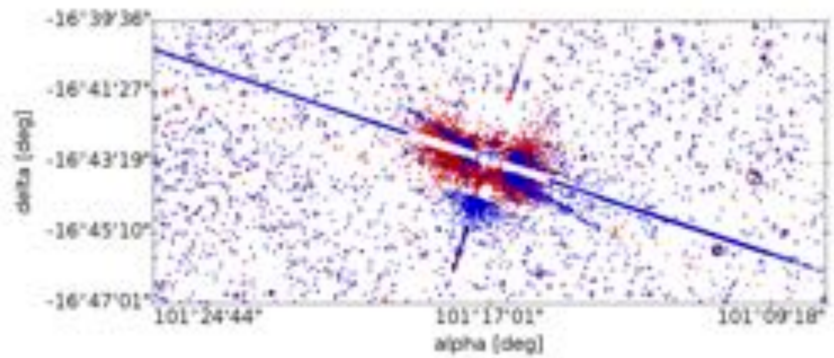
DR1 - Quantile positional precisions in mas for the 1.1 billion non-TGAS sources

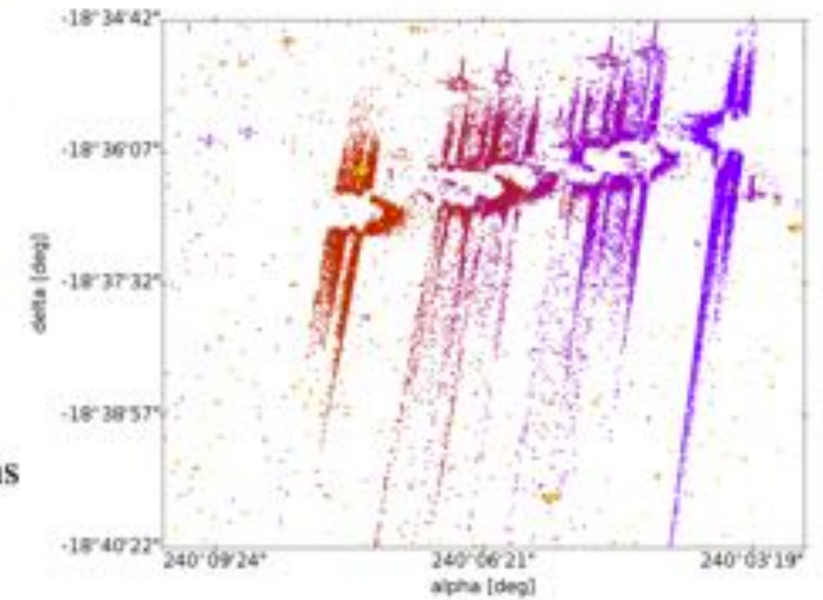
Gaia DPAC

G mag	fraction	10 %	50 %	90 %
< 16	7 %	0.1	0.3	5.3
16-17	7 %	0.2	0.5	12.1
17-18	12 %	0.3	0.8	12.4
18-19	21 %	0.5	1.5	13.7
19-20	30 %	0.9	2.7	16.6
20-21	22 %	1.9	2.4	21.5
All	100 %	0.35	0.60	16.3

Slide from Coryn Bailer-Jones

Spurious sources and Gaia cross-match

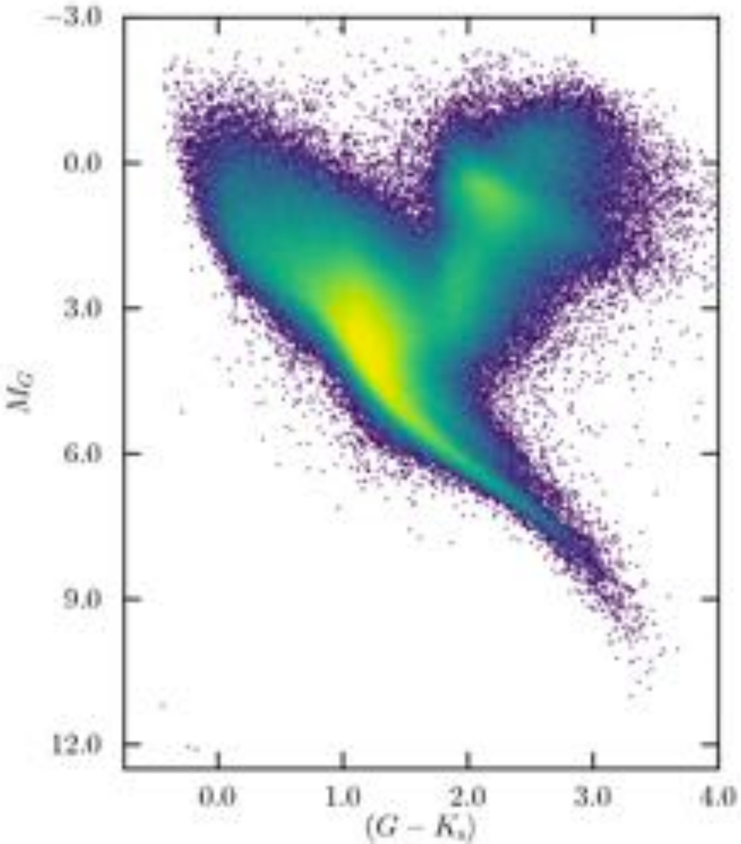




- Bright objects cause spurious on-board detections
- Vast majority removed during data processing
- Small fraction of Gaia DR1 sources may have photometry affected by inclusion of a spurious transit
- Details: Fabricius et al., A&A, 2016

A. Brown

HR diagram from TGAS stars



Full Gaia DR1 data set

- 1 million stars with parallaxes precise to ≤ 20%
- 90% inside 590 pc
- Future
  - ∼ 10 million parallaxes precise to 1%
  - ∼ 150 million precise to 10%
  - ∼ 280 million precise to 20%

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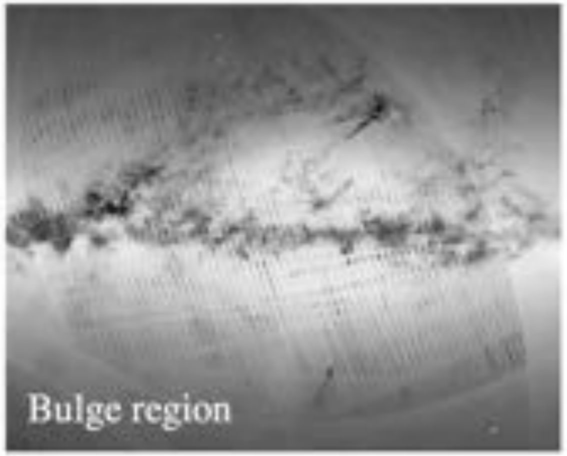
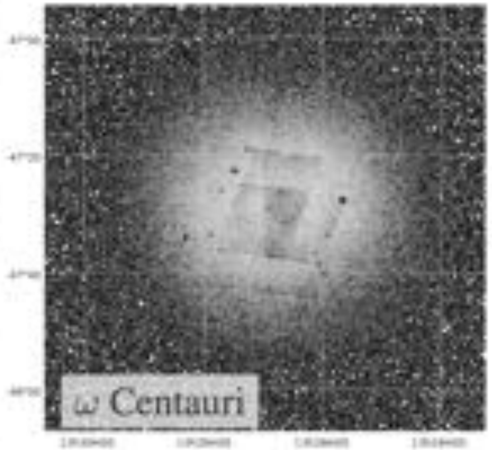
Gaia DR1 completeness

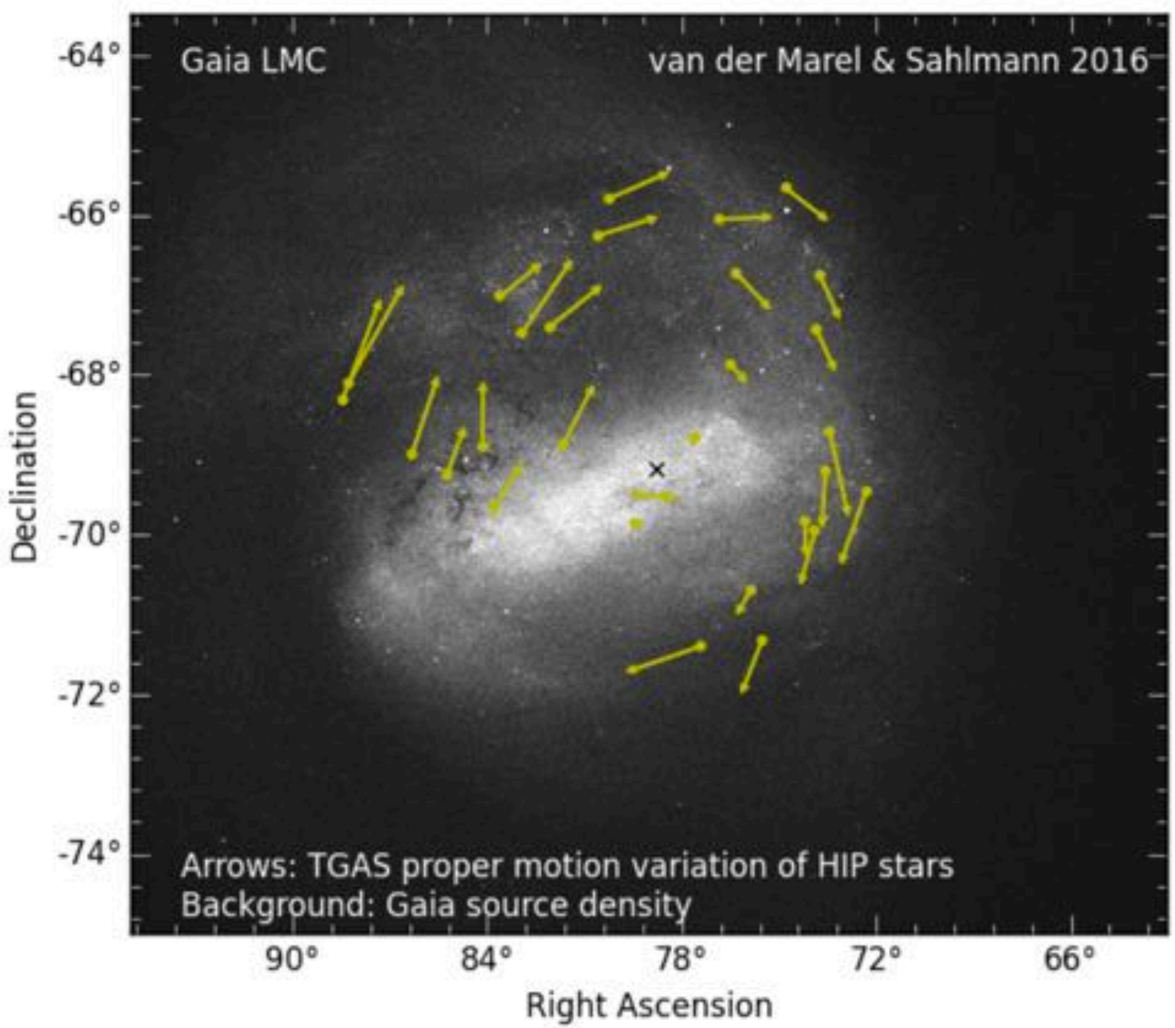




- Ill-defined and celestial position dependent faint limit
- Scanning law + filtering on data quality ⟶ source density artifacts
- High density regions (few 100 000 stars/deg^2) affected by several factors
- Below 4 arcsec separation many secondary components of binaries missing
- Many bright stars missing at $G \lesssim 7$
- High proper motion stars ($\mu > 3.5$) arcsec yr^{-1} missing
- See section 6.2 of Gaia DR1 paper for details (arXiv:1609.04172)

A. Brown

Very first science



A. Brown

Gaia DR1-Papers on astroph

- **First Gaia Local Group Dynamics: Magellanic Clouds Proper Motion and Rotation**, Roeland P. van der Marel, Johannes Sahlmann
- **A Direct Measurement with Gaia of Radius Inflation in the Pleiades and its Relation to Rotation and Lithium Depletion**, Garrett Somers, Keivan G. Stassun
- **A test of Gaia Data Release 1 parallaxes: implications for the local distance scale**, Stefano Casertano, Adam G. Riess, Beatrice Bucciarelli, Mario G. Lattanzi
- **Accurate, Empirical Radii and Masses of Planets with Gaia Parallaxes**, Keivan G. Stassun (1,2), Karen A. Collins (1), B. Scott Gaudi (3) ((1)
- **A first view with GAIA on KIC 8462852 - distance estimates and a comparison to other F stars**, Michael Hippke, Daniel Angerhausen
- **TGAS Error Renormalization from the RR Lyrae Period-Luminosity Relation**, Andrew Gould (MPIA, KASI, OSU), Juna A. Kollmeier (OCIW), Branimir Sesar (MPIA)
- **Estimating distances from parallaxes. III. Distances of two million stars in the Gaia DR1 catalogue**, Tri L. Astraatmadja (1,2), Coryn A. L. Bailer-Jones (2) ((1)

Gaia DR1-Papers on astroph

- **Gaia Data Release 1: The reference frame and the optical properties of ICRF sources**, F. Mignard, S. Klioner, L. Lindegren, U. Bastian, A. Bombrun, J. Hernandez, D. Hobbs, U. Lammers, D. Michalik, M. Ramos-Lerate, M. Biermann, A. Butkevich, G. Comoretto, E. Joliet, B. Holl, A. Hutton, P. Parsons, H. Steidelmueller, A. Andrei, G. Bourda, P. Charlot
- **Connecting VLBI and Gaia celestial reference frames**, Zinovy Malkin
- **A test field for Gaia. Radial velocity catalogue of stars in the South Ecliptic Pole**, Y. Frémat, M. Altmann, E. Pancino, C. Soubiran, P. Jofré, Y. Damerdji, U. Heiter, F. Royer, G. Seabroke, R. Sordo, S. Blanco-Cuaresma, G. Jasniewicz, C. Martayan, F. Thévenin, A. Vallenari, R. Blomme, M. David, E. Gosset, D. Katz, Y. Viala, S. Boudreault, T. Cantat-Gaudin, A. Lobel, K. Meisenheimer, T. Nordlander, G. Raskin, P. Royer, J. Zorec
- **The Rotation-Metallicity Relation for the Galactic Disk as Measured in the Gaia DR1 TGAS and APOGEE Data**, Carlos Allende Prieto, Daisuke Kawata, Mark Cropper
- **Asteroseismic versus Gaia distances: a first comparison**, J. De Ridder, G. Molenberghs, L. Eyer, C. Aerts
- **Inferring the three-dimensional distribution of dust in the Galaxy with a non-parametric method: Preparing for Gaia**, S. Rezaei Kh., C.A.L. Bailer-Jones, R.J. Hanson, M. Fouesneau

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- **Detection of a dearth of stars with zero angular momentum in the solar neighbourhood**, Jason A. S. Hunt, Jo Bovy, Raymond G. Carlberg
- **Astrometry with Hubble Space Telescope Fine Guidance Sensors - A Review**, G. Fritz Benedict, Barbara E. McArthur, Edmund P. Nelan, Thomas E. Harrison
- **Evidence for a systematic offset of −0.25 mas in the Gaia DR1 parallaxes**, Keivan G. Stassun (1,2), Guillermo Torres (3) ((1)
- **Tracing the Hercules stream with Gaia and LAMOST: new evidence for a fast bar in the Milky Way**, Giacomo Monari, Daisuke Kawata, Jason A. S. Hunt, Benoit Famaey
- **A revised moving cluster distance to the Pleiades open cluster**, P.A.B. Galli, E. Moraux, H. Bouy, J. Bouvier, J. Olivares, R. Teixeira
- **The canonical Luminous Blue Variable AG Car and its neighbor Hen 3-519 are much closer than previously assumed**, Nathan Smith (1), Keivan G. Stassun (2,3) ((1)
- **Galactic rotation in Gaia DR1**, Jo Bovy

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- **Rotating Stars from Kepler Observed with Gaia DR1**, James R. A. Davenport
- **A box full of chocolates: The rich structure of the nearby stellar halo revealed by Gaia and RAVE**, Amina Helmi, Jovan Veljanoski, Maarten A. Breddels, Hao Tian, Laura V. Sales
- **The Gaia DR1 Mass-Radius Relation for White Dwarfs**, P.-E. Tremblay, N. Gentile-Fusillo, R. Raddi, S. Jordan, C. Besson, B. T. Gaensicke, S. G. Parsons, D. Koester, T. Marsh, R. Bohlin, J. Kalirai
- **Distance Dependent Offsets between Parallaxes for Nearby Stars and Gaia DR1 Parallaxes**, Wei-Chun Jao, Todd J. Henry, Adric R. Riedel, Jennifer G. Winters, Kenneth J. Slatten, Douglas R. Gies,
- **Fast rotating group of stars observed in Gaia TGAS: a signature driven by the Perseus arm?**, Jason A. S. Hunt, Daisuke Kawata, Giacomo Monari, Robert J. J. Grand, Benoit Famaey, Arnaud Siebert
- **The Galaxy Kinematics from OB Stars with Proper Motions from the Gaia DR1 Catalog**, V.V. Bobylev, A.T. Bajkova
- **The Galaxy Kinematics from the Cepheids with the Proper Motions from the GAIA DR1 Catalog**, V.V. Bobylev

Gaia DR1-Papers on astroph

- **Gaia data release 1: Principles of the photometric calibration of the G band**, J.M. Carrasco, D.W. Evans, P. Montegriffo, C. Jordi, F. van Leeuwen, M. Riello, H. Voss, F. De Angeli, G. Busso, C. Fabricius, C. Cacciari, M. Weiler, E. Pancino, A.G.A. Brown, G. Holland, P. Burgess, P. Osborne, G. Altavilla, M. Gebran, S. Ragaini, S. Galleti, G. Cocozza, S. Marinoni, M. Bellazzini, A. Bragaglia, L. Federici, L. Balaguer-Núñez
- **On significance of VLBI/Gaia offsets**, L. Petrov (Astrogeo Center), Y.Y. Kovalev (ASC Lebedev, MPIfR),
- **VLBI-Gaia offsets favour parsec-scale jet direction in Active Galactic Nuclei**, Y.Y. Kovalev (ASC Lebedev, MPIfR), L. Petrov (Astrogeo Center), A.V. Plavin (ASC Lebedev, Fiztech)
- **Tycho-Gaia Astrometric Solution parallaxes and proper motions for 5 Galactic globular cluster**, Laura L. Watkins, Roeland P. van der Marel (STScI)
- **Clouds, Streams and Bridges. Redrawing the blueprint of the Magellanic System with Gaia DR1**, Vasily Belokurov, Denis Erkal, Alis J. Deason, Sergey E. Koposov, Francesca De Angeli, Dafydd Wyn Evans, Filippo Fraternali, Dougal Mackey
- **The Clouds are breaking: tracing the Magellanic system with Gaia DR1 Mira variables**, Alis J. Deason (Durham), Vasily Belokurov, Denis Erkal, Sergey E. Koposov (Cambridge), Dougal Mackey (ANU)

Gaia DR1-Papers on astroph

- **TGAS search for Large Magellanic Cloud runaway supergiant stars:Candidate hypervelocity star discovery, and the nature of R71**, Daniel J. Lennon, Roeland P. van der Marel, Mercedes Ramos Lerate, William O'Mullane, Johannes Sahlmann
- **A Probabilistic Approach to Fitting Period-Luminosity Relations and Validating Gaia Parallaxes**Branimir Sesar, Morgan Fouesneau, Adrian M. Price-Whelan, Coryn A. L. Bailer-Jones, Andy Gould, Hans-Walter Rix
- **Gaia Assorted Mass Binaries Long Excluded from SLoWPoKES (GAMBLES): Identifying Wide Binary Pairs with Components of Diverse Mass**, Ryan J. Oelkers, Keivan G. Stassun, Saurav Dhital
- **Gaia 1 and 2. A pair of new satellites of the Galaxy**, S. E. Koposov, V. Belokurov , G. Torrealba
- **Gaia's view of the λ Boo star puzzle**, Simon J. Murphy, Ernst Paunzen
- **Gliese 710 will pass the Sun even closer**, Filip Berski and Piotr A. Dybczyński
- **The surface brightness -- color relations based on eclipsing binary stars: toward sub 1% precision in angular diameter predictions**, Dariusz Graczyk, Piotr Konorski, Grzegorz Pietrzynski, Wolfgang Gieren, Jesper Storm, Nicolas Nardetto, Alexandre Gallenne, Pierre F. L. Maxted

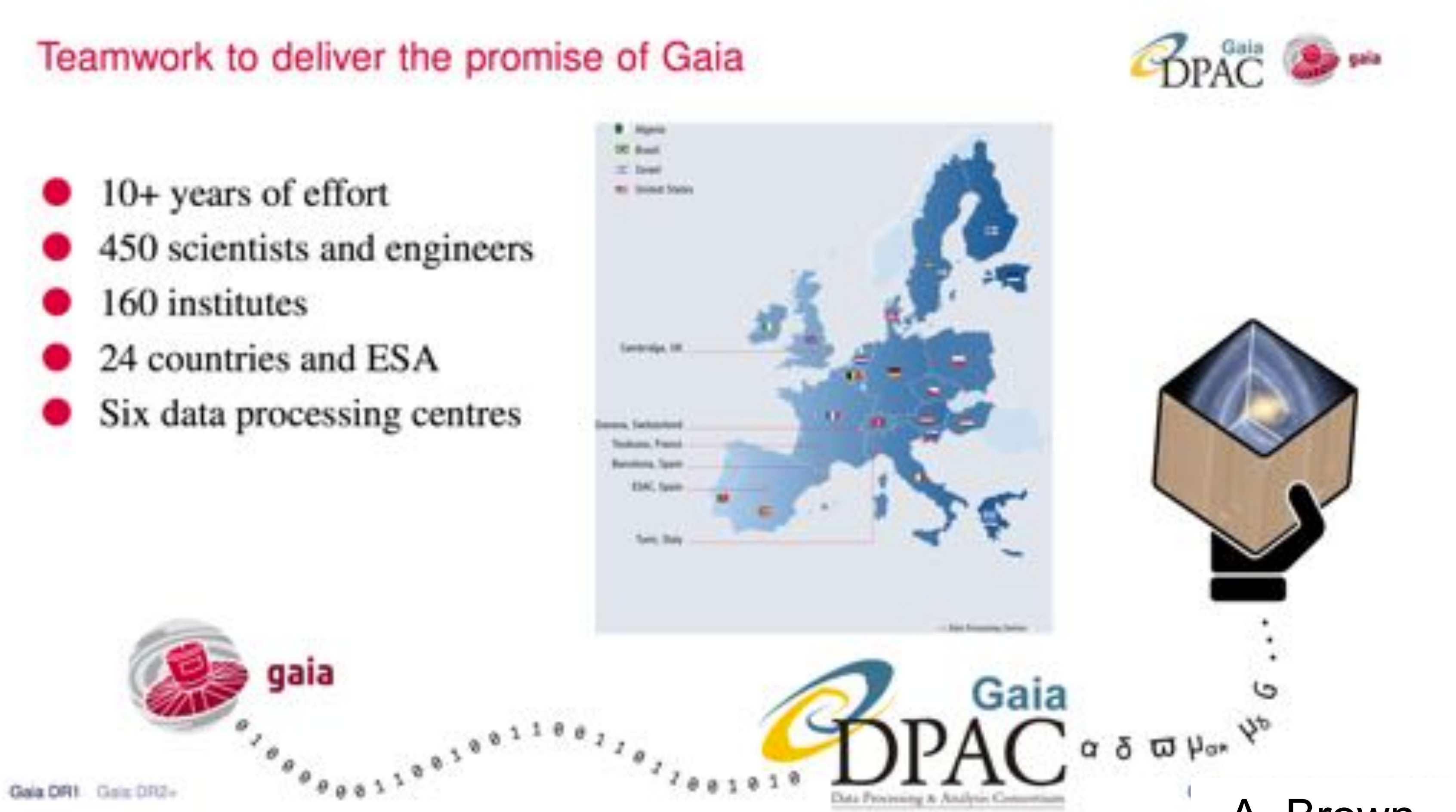
Gaia DR1-Papers on astroph

- **Gaia and Variable Stars**, A. Udalski, I. Soszyński, D.M. Skowron, J. Skowron, P. Pietrukowicz, P. Mróz, R. Poleski, M.K. Szymański, S. Kozłowski, Ł. Wyrzykowski, K. Ulaczyk, M. Pawlak
- **Co-moving stars in Gaia DR1: An abundance of very wide separation co-moving pairs**, Semyeong Oh, Adrian M. Price-Whelan, David W. Hogg, Timothy D. Morton, David N. Spergel
- **New runaway O-type stars in the first Gaia Data Release**, J. Maíz Apellániz, R. H. Barbá, S. Simón-Díaz, I. Negueruela, E. Trigueros Páez
- **Using red clump stars to correct the Gaia DR1 parallaxes,** Guy R. Davies, Mikkel N. Lund, Andrea Miglio, Yvonne Elsworth, James S. Kuszlewicz, Thomas S.H. North, Ben Rendle, William J. Chaplin, Thaíse S. Rodrigues, Tiago L. Campante, Léo Girardi, Steven J. Hale, Oliver Hall, Caitlin D. Jones, Steven D. Kawaler, Ian Roxburgh, Mathew Schofield
- **Hot Stuff for One Year (HSOY) - A 580 million star proper motion catalogue derived from Gaia DR1 and PPMXL**, Martin Altmann, Siegfried Roeser, Markus Demleitner, Ulrich Bastian, Elena Schilbach
- **The Impact of Gaia DR1 on Asteroseismic Inferences from Kepler**, Travis Metcalfe, Orlagh Creevey, Jennifer van Saders

Gaia DR1-Papers on astroph

- **CCD astrometric observations of Amalthea and Thebe in the Gaia era**, Robert, V.; Saquet, E.; Colas, F.; Arlot, J.-E.
- **Large Magellanic Cloud Near-Infrared Synoptic Survey. IV. Leavitt Laws for Type II Cepheid Variables**, Anupam Bhardwaj, Lucas M. Macri, Marina Rejkuba, Shashi M. Kanbur, Chow-Choong Ngeow, Harinder P. Singh

Teamwork



A. Brown

Gaia Sky Flight
APOD: Here comes the Sun

Gaia: April 2018

- Five-parameter astrometric solutions for all sources with acceptable formal standard errors (>10^9 anticipated), and positions (α, δ) for sources for which parallaxes and proper motions cannot be derived.
- G and integrated G_{BP} and G_{RP} photometric fluxes and magnitudes for all sources.
- Median radial velocities for sources brighter than G_{RVS}=12 mag.
- For stars brighter than G=17 mag estimates of the effective temperature and, where possible, line-of-sight extinction will be provided, based on the above photometric data.
- Photometric data for a sample of variable stars.
- Epoch astrometry for a pre-selected list of >10,000 asteroids

Gaia: Transits

KNOWN EXOPLANETARY TRANSITS IN GAIA DATA

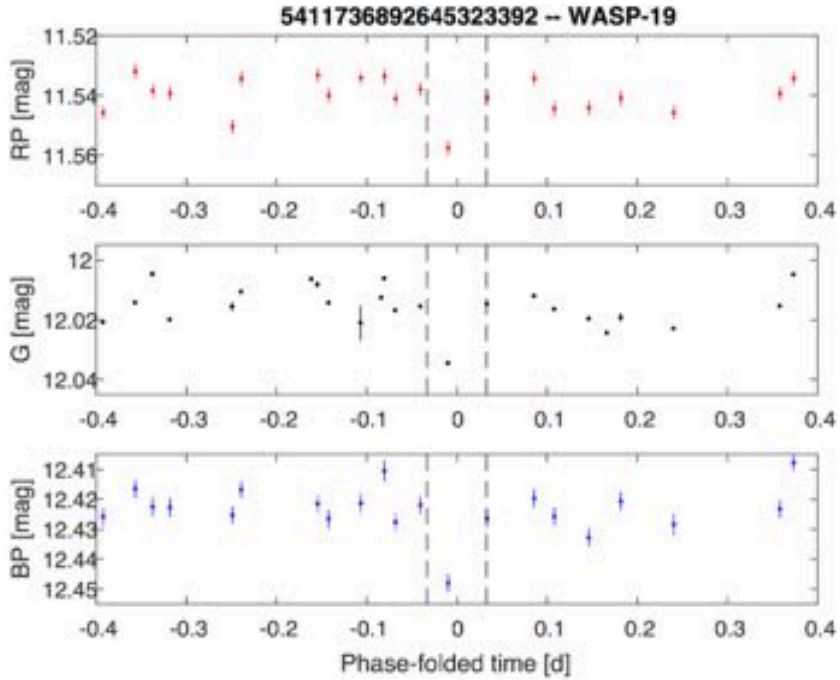


Figure 1: Gaia folded light-curve of WASP-19b in the bands RP, G and BP. The light-curves are shifted to zero transit phase, and folded by the known period. The vertical dashed lines mark the times of transit ingress and egress. (Image credit: ESA/Gaia/DPAC/CU7) https://www.cosmos.esa.int/web/gaia/iow_20170209

Gaia: Transits

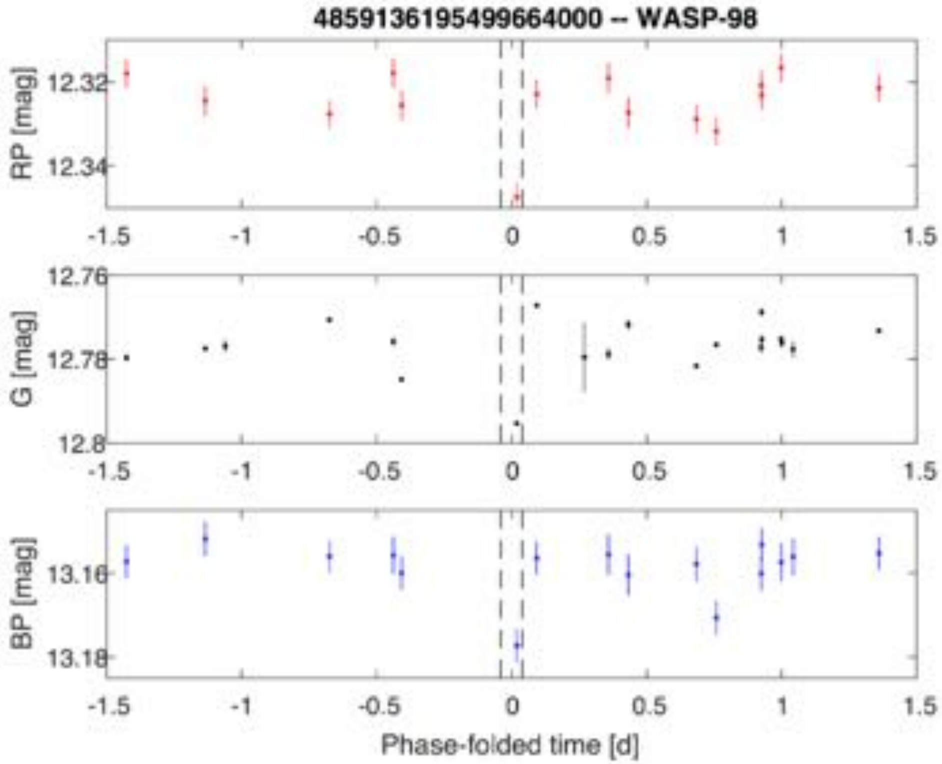
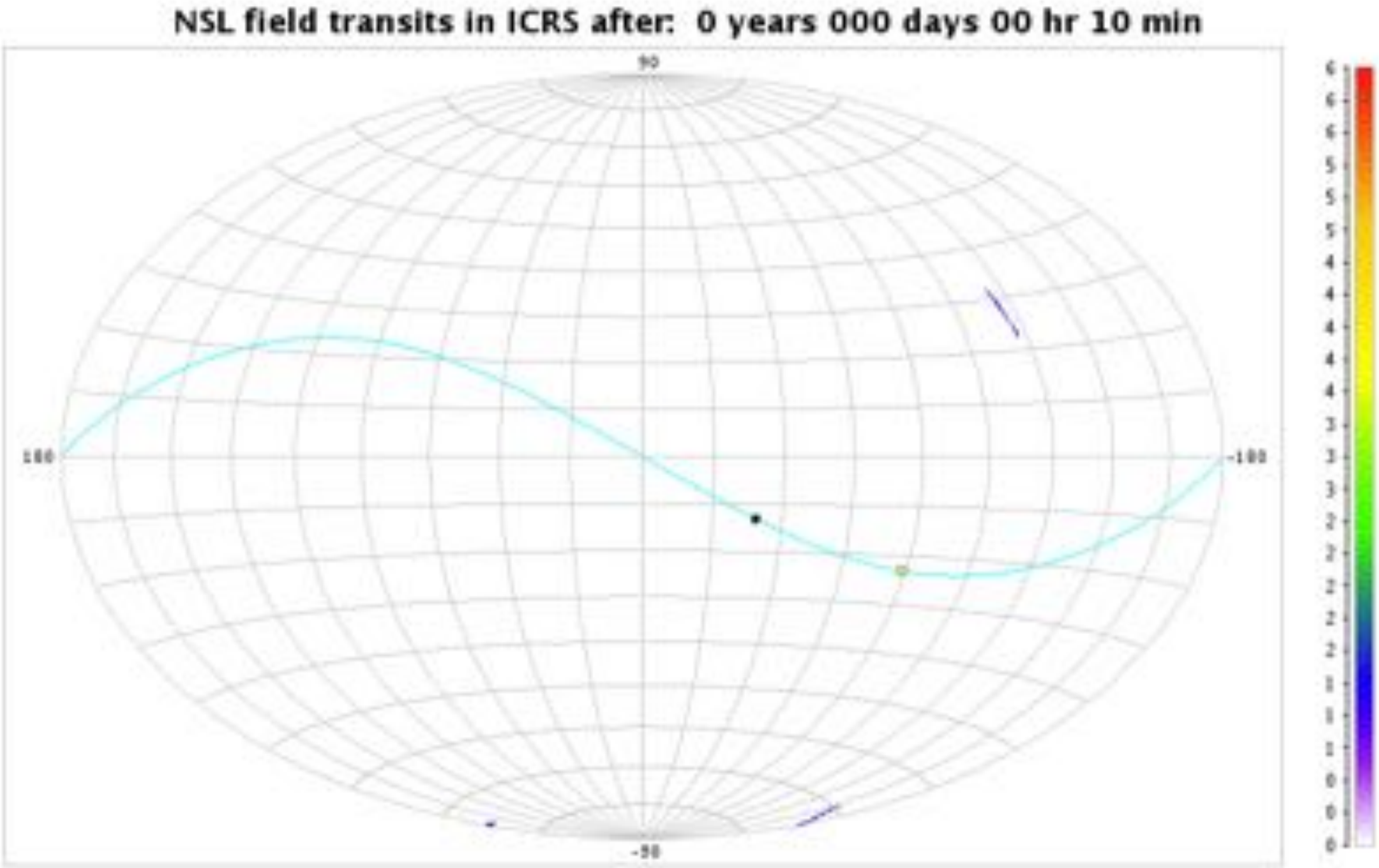


Figure 2: Gaia folded light-curve of WASP-98b in the bands RP, G and BP. The light-curves are shifted to zero transit phase, and folded by the known period. The vertical dashed lines mark the times of transit ingress and egress. (Image credit: ESA/Gaia/DPAC/CU7)

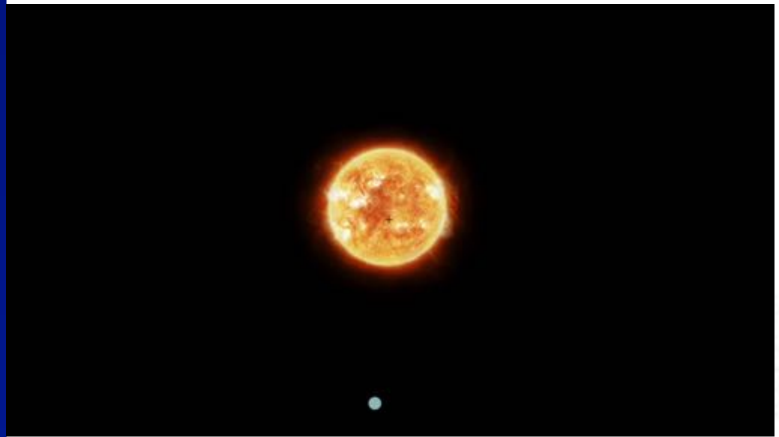
aia/iow_20170209

Gaia Scanning law

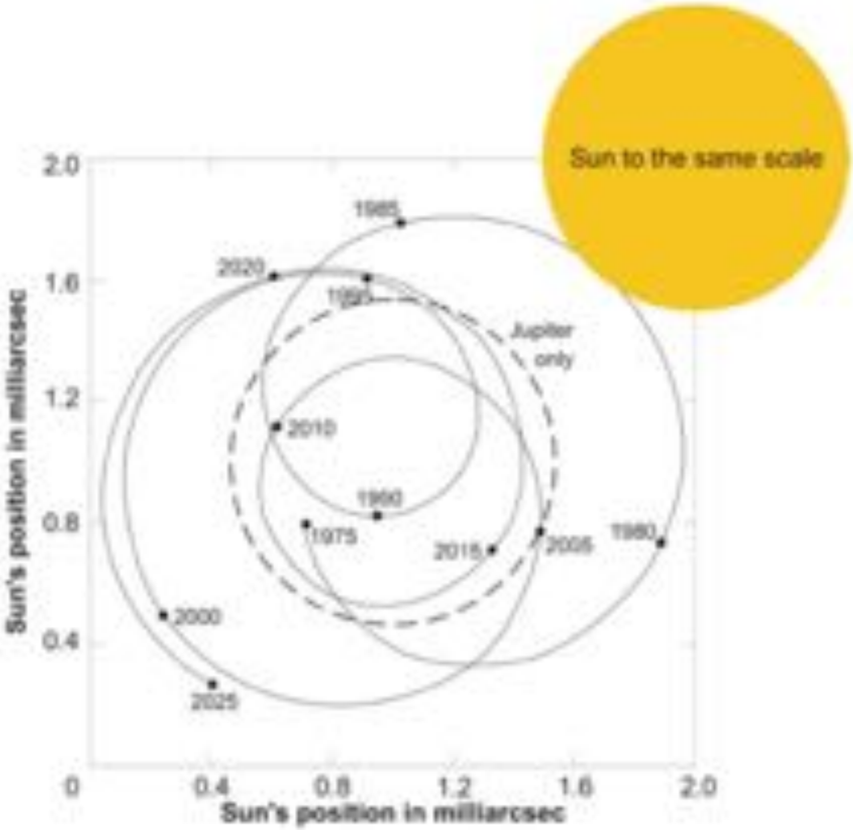


Animation: Berry Holl, Lund

Exoplanets



(Animation: ESA)



Wobbling of the Sun seen from 10 pc distance

http://innumerableworlds.files.wordpress.com/2009/04/
sunwobble.jpg?w=460&h=431