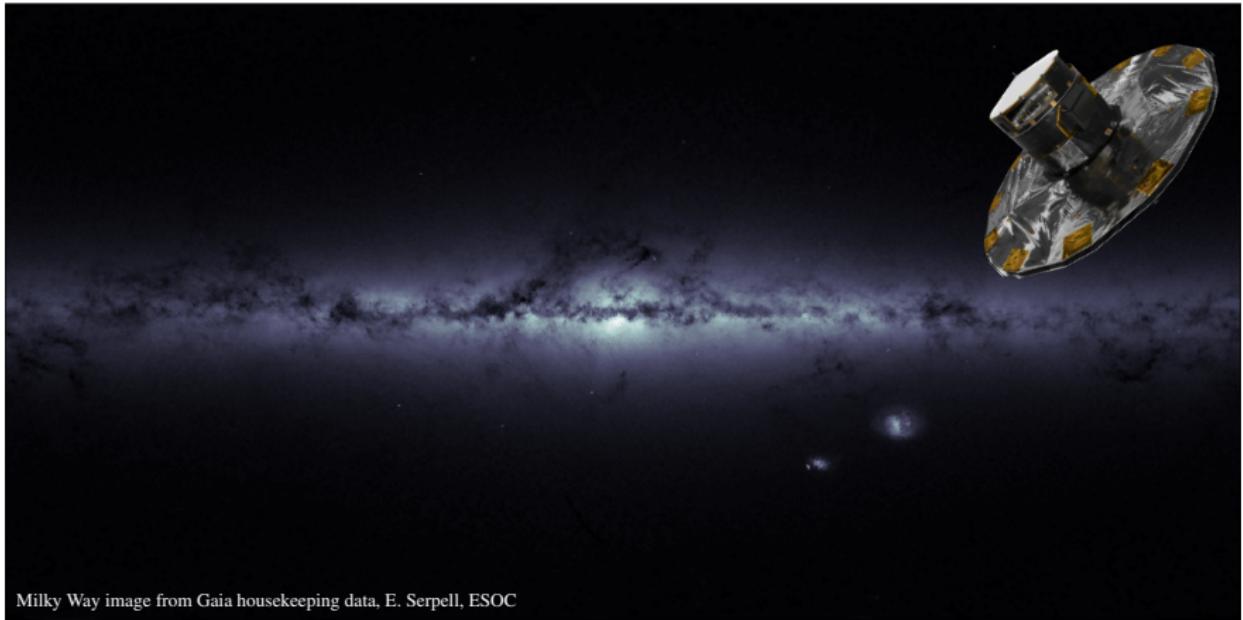


# Gaia — one year of science operations

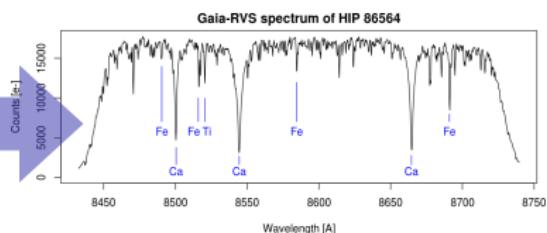
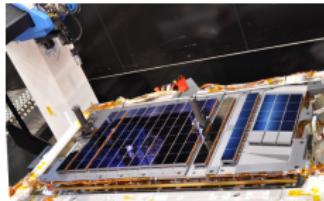
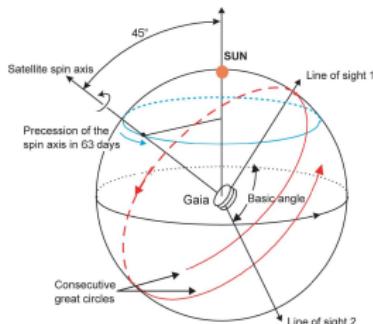
Anthony Brown

Sterrewacht Leiden, Leiden University  
brown@strw.leidenuniv.nl

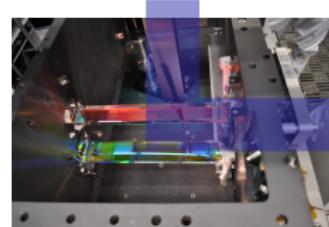
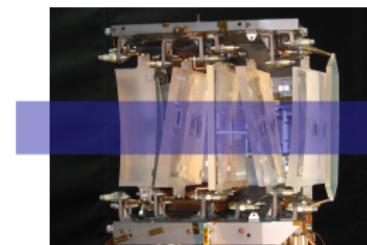
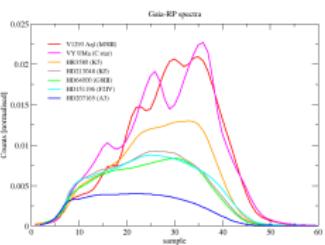
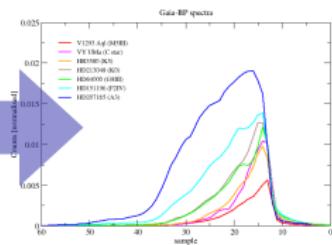


Milky Way image from Gaia housekeeping data, E. Serpell, ESOC

# Gaia instruments and measurements



Figures: ESA/Gaia/DPAC/Airbus DS



# One year into science observations

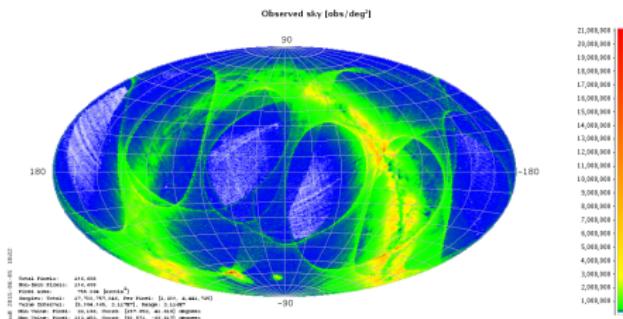
- In 5-year nominal science operations phase since July 18 2014

- Data collection stats:

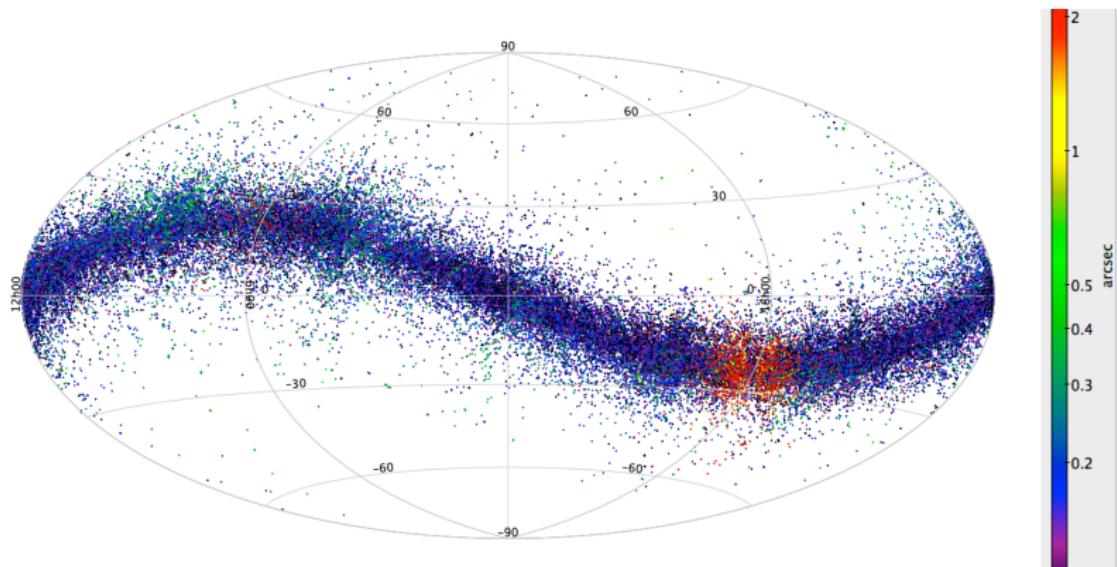
- ▶ 272 billion astrometric measurements
- ▶ 54.4 billion photometric (BP/RP) measurements
- ▶ 5.4 billion RVS spectra

- Survey limits

- ▶ Astrometry and photometry for  $2 < G < 20.7$  mag
- ▶ Stars brighter than  $G = 3$  captured with Sky Mapper imaging
- ▶ Spectra up to  $G_{\text{RVS}} = 16.2$  (and  $G > 2$  mag)

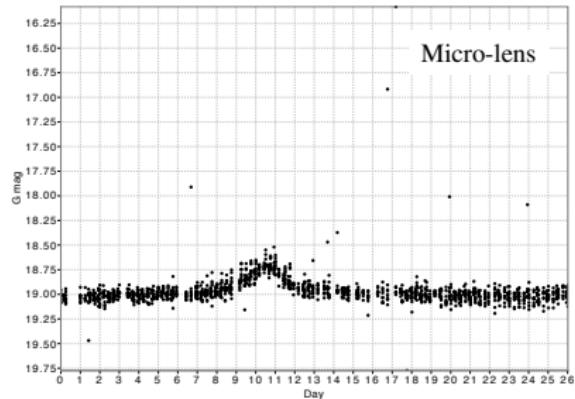
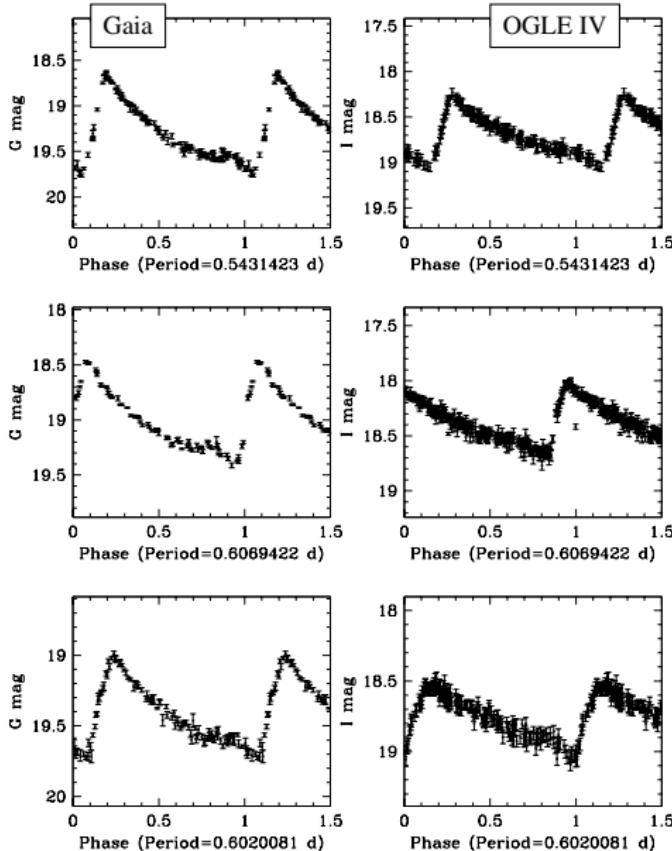


Figures courtesy DPAC/CU3/IDT team



Credits: SA/Gaia/DPAC/CU4, L. Galluccio, F. Mignard, P. Tanga (Observatoire de la Côte d'Azur)

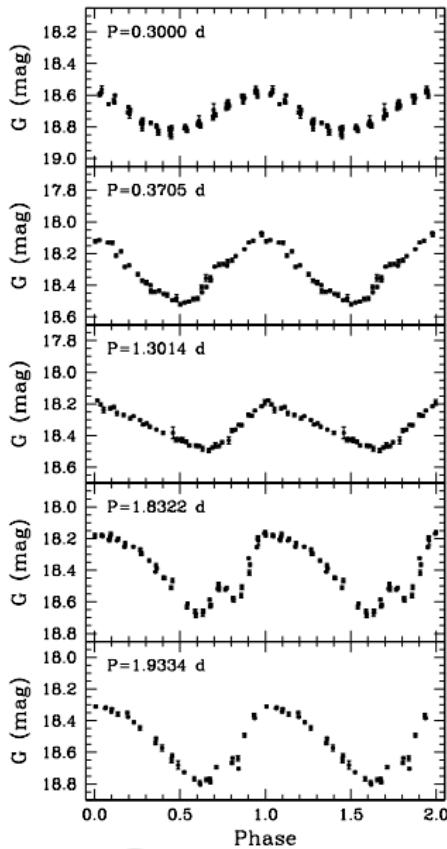
- Test of asteroid detection chain on 50 000 known asteroids
  - ▶ ~ 90% completeness
  - ▶ colour coding shows error relative to predicted position (with larger errors toward Galactic centre region)



Credits: ESA/Gaia/DPAC/Dafydd Wyn Evans and Marco Riello

Illustration of photometric data quality: 4 weeks of Gaia data with preliminary calibrations compared to OGLE IV

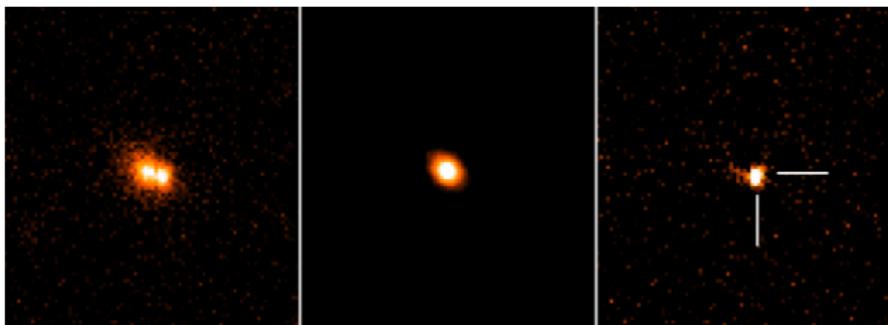
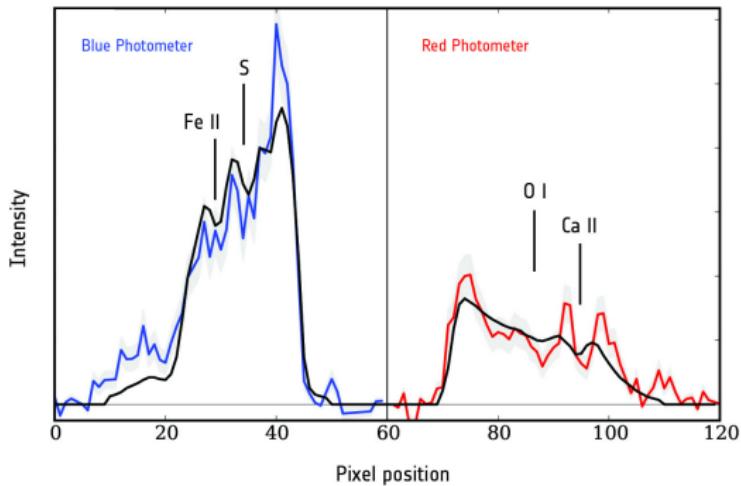
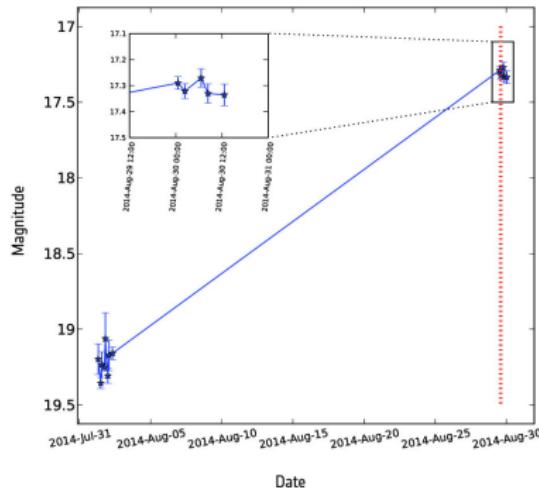
Credits: ESA/Gaia/DPAC/CU5/CU7/INAF-OABo, Gisella Clementini, Dafydd Evans, Laurent Eyer, Krzysztof Nienartowicz, Lorenzo Rimoldini and the Geneva CU7/DPCG and CU7/INAF-OACN teams



Examples of Cepheids with period determined from Gaia observations.

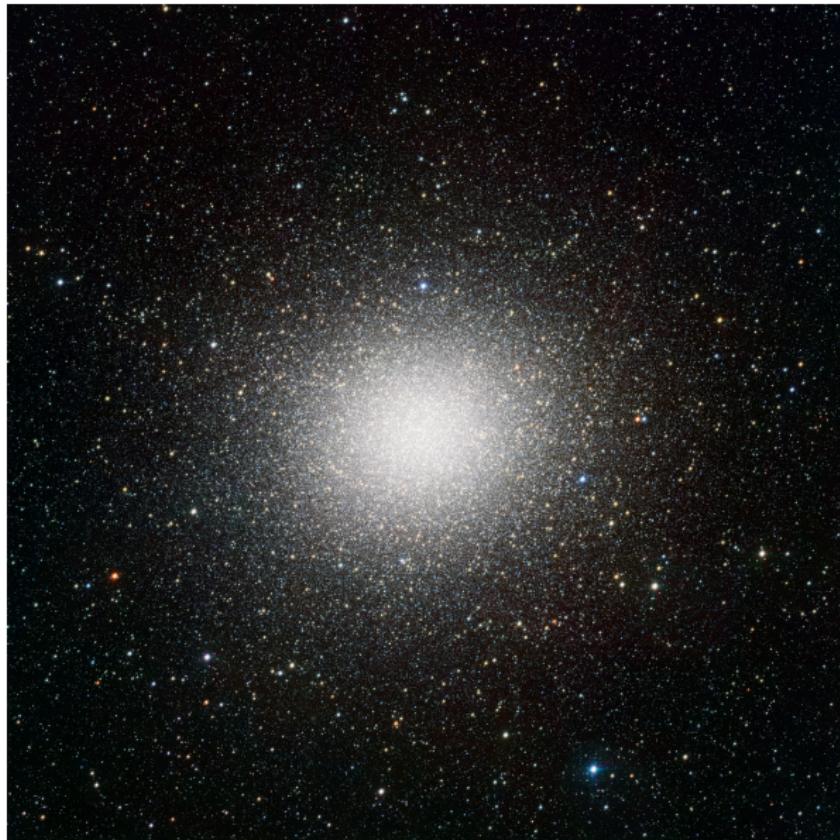
Credits: ESA/Gaia/DPAC/CU5/DPCI/CU7/INAF-OABo/INAF-OACn Gisella Clementini, Vincenzo Ripepi, Silvio Leccia, Laurent Eyer, Lorenzo Rimoldini, Isabelle Lecoeur-Taibi, Nami Mowlavi, Dafydd Evans, Geneva CU7/DPCG and the whole CU7 team. The photometric data reduction was done with the PhotPipe pipeline at DPCI; processing data were received from the IDT pipeline at DPCE

# First supernova discovery

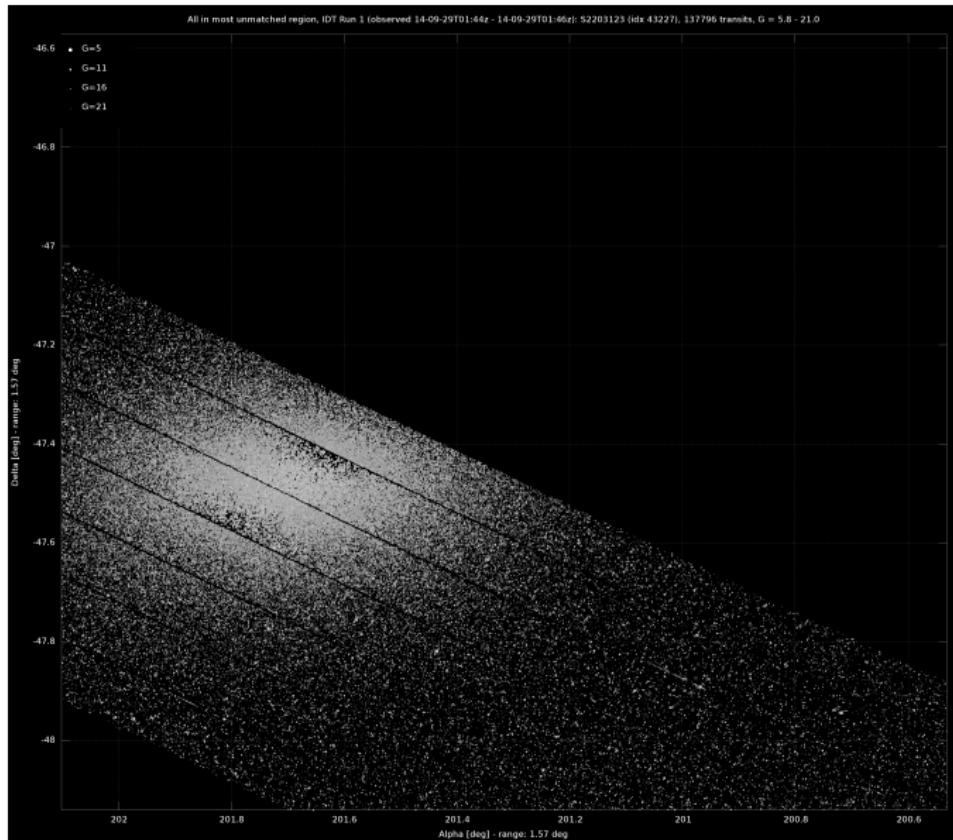


Credits: M. Fraser/ S. Hodgkin/ L. Wyrzykowski/  
H. Campbell/ N. Blagorodnova/  
Z. Kostrzewska-Rutkowska/ Liverpool Telescope/  
SDSS/ ESA/ Gaia/ DPAC

# Omega Centauri

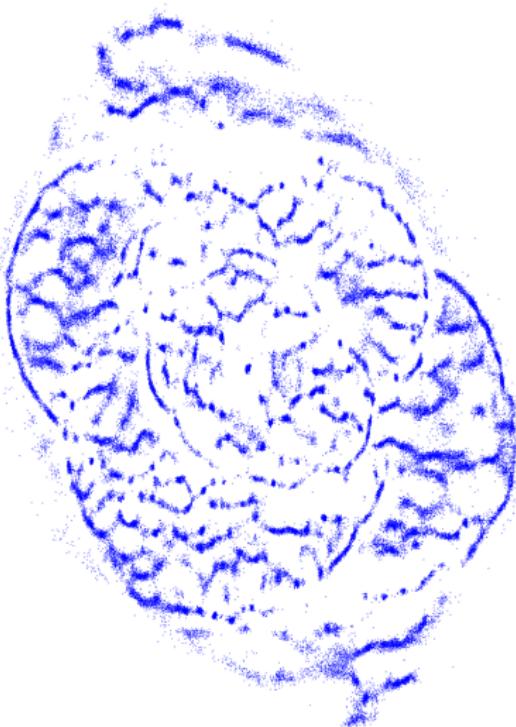


Credits: ESO/INAF-VST/OmegaCAM

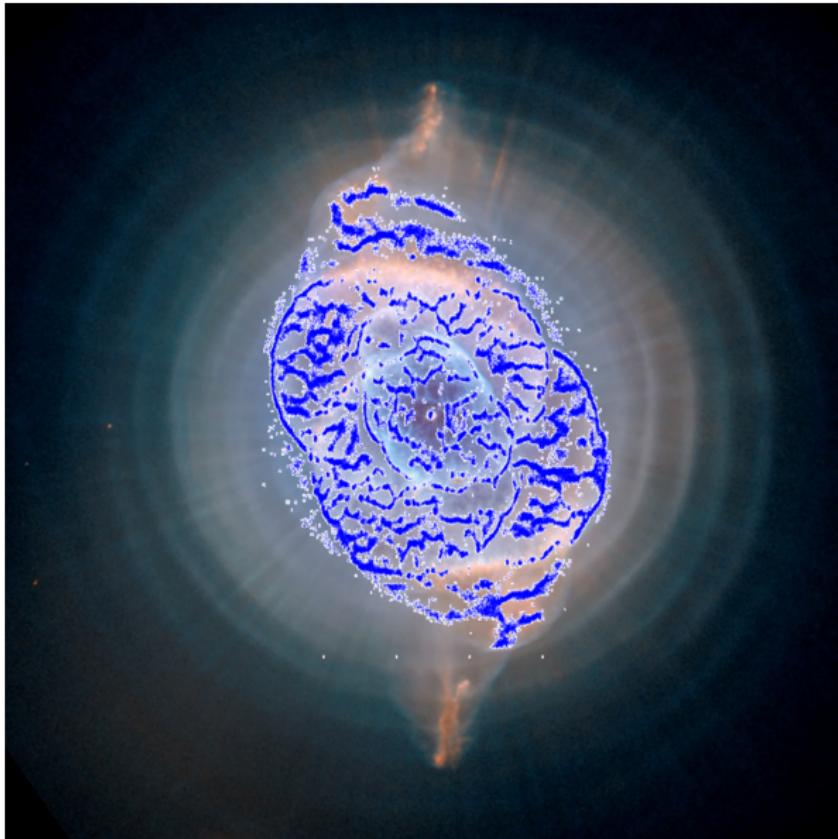


The Gaia view

Credits: ESA/ Gaia/ DPAC/ UB/ IEEC



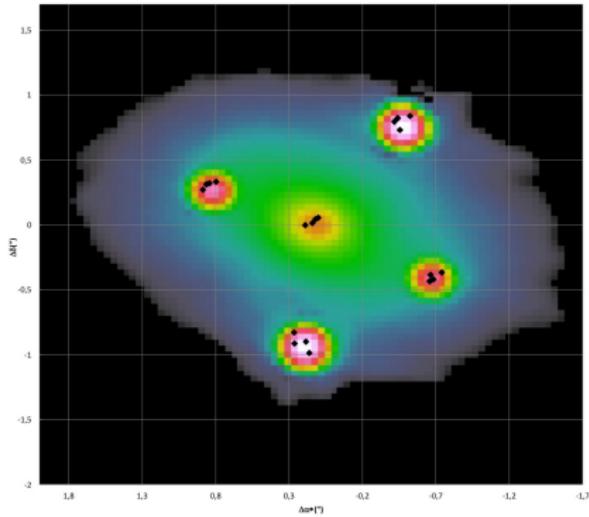
Credits: ESA/ Gaia/ DPAC/ UB/ IEEC



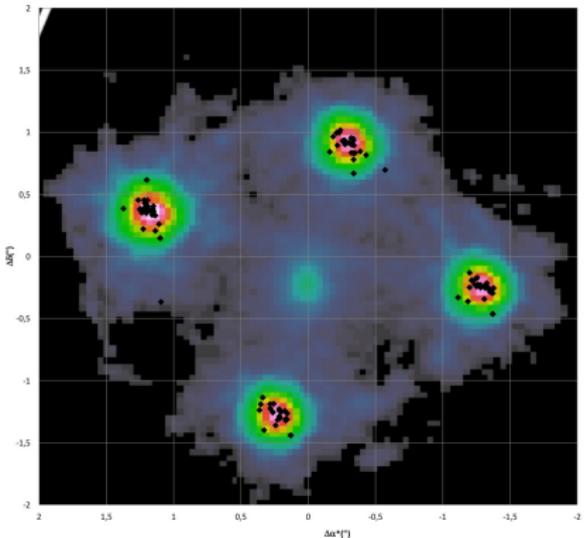
Credits: NASA, ESA, HEIC, and The Hubble Heritage Team (STScI/AURA)

Credits: ESA/ Gaia/ DPAC/ UB/ IEEC

## Einstein's cross (Q2237+030)



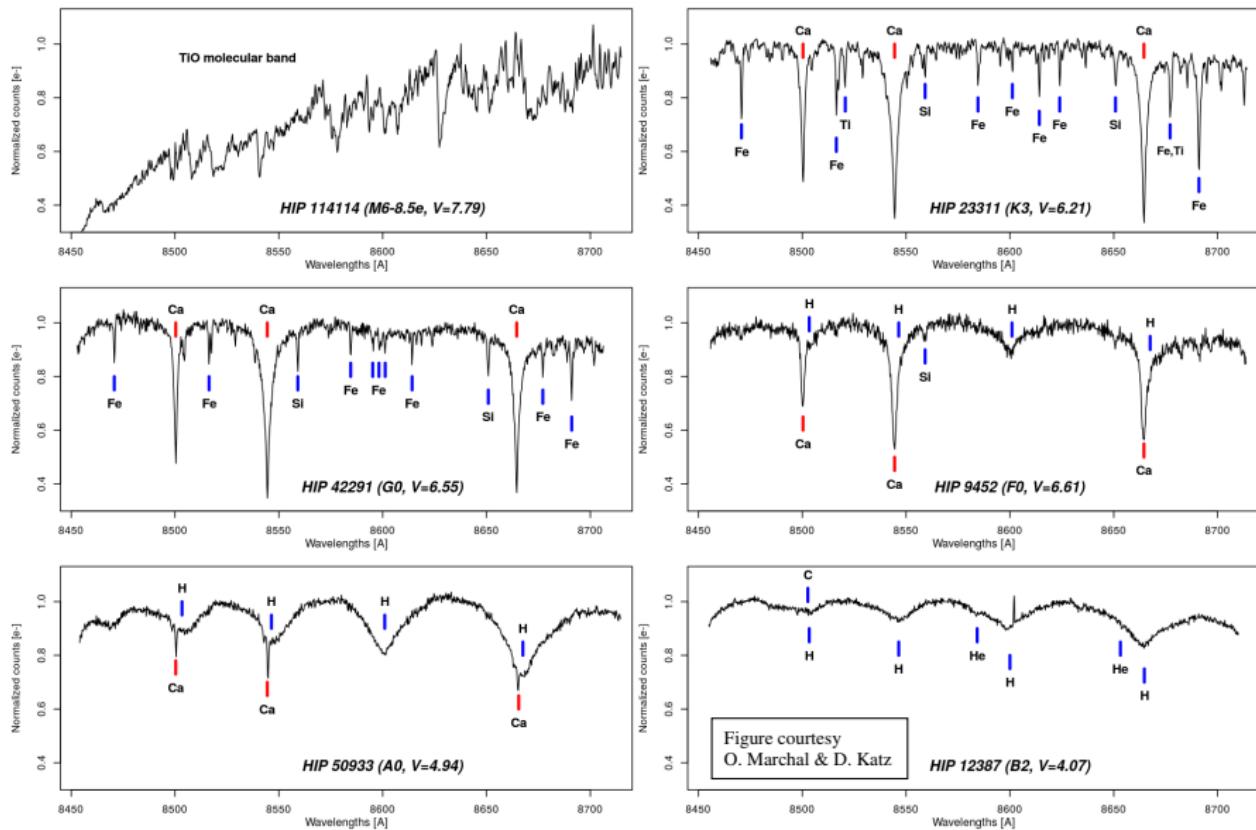
## HE0435-1223



Credits: ESA/Gaia/DPAC/Christine Ducourant, Jean-Francois Lecampion (LAB/Observatoire de Bordeaux), Alberto Krone-Martins (SIM/Universidade de Lisboa, LAB/Observatoire de Bordeaux), Laurent Galluccio, Francois Mignard (Observatoire de la Côte d'Azur, Nice)

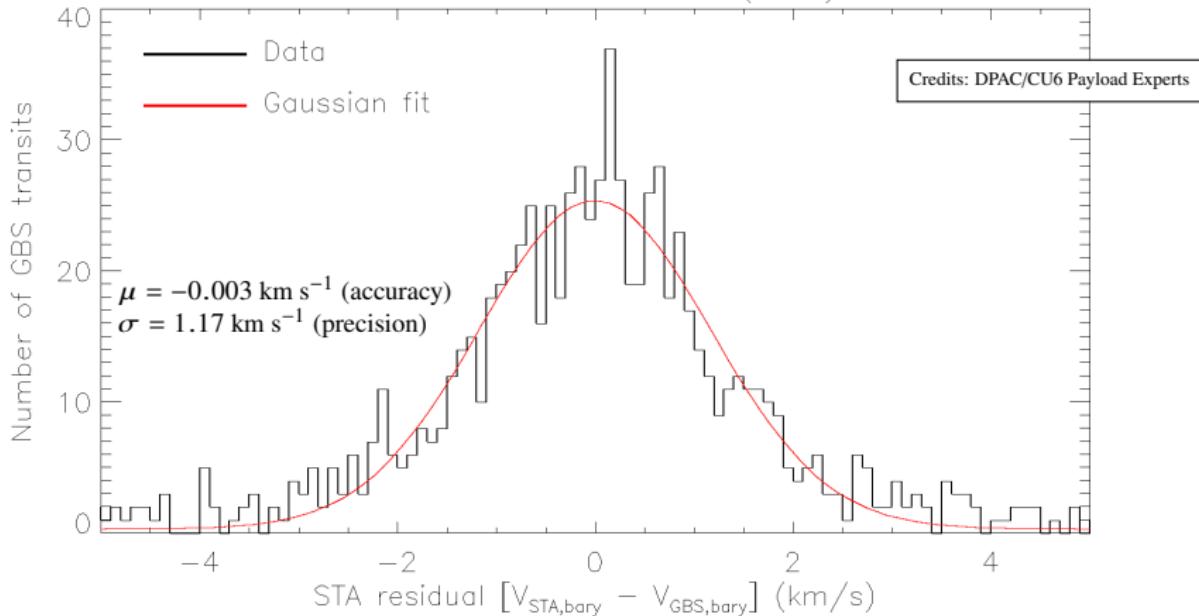
- Comparison to ICRF sources shows that crude Initial Data Treatment astrometry is already good to  $\sim 30$  mas RMS.
- Many new multiply images QSOs can be identified with Gaia

## Preliminary RVS performance assessment



# Preliminary RVS performance assessment

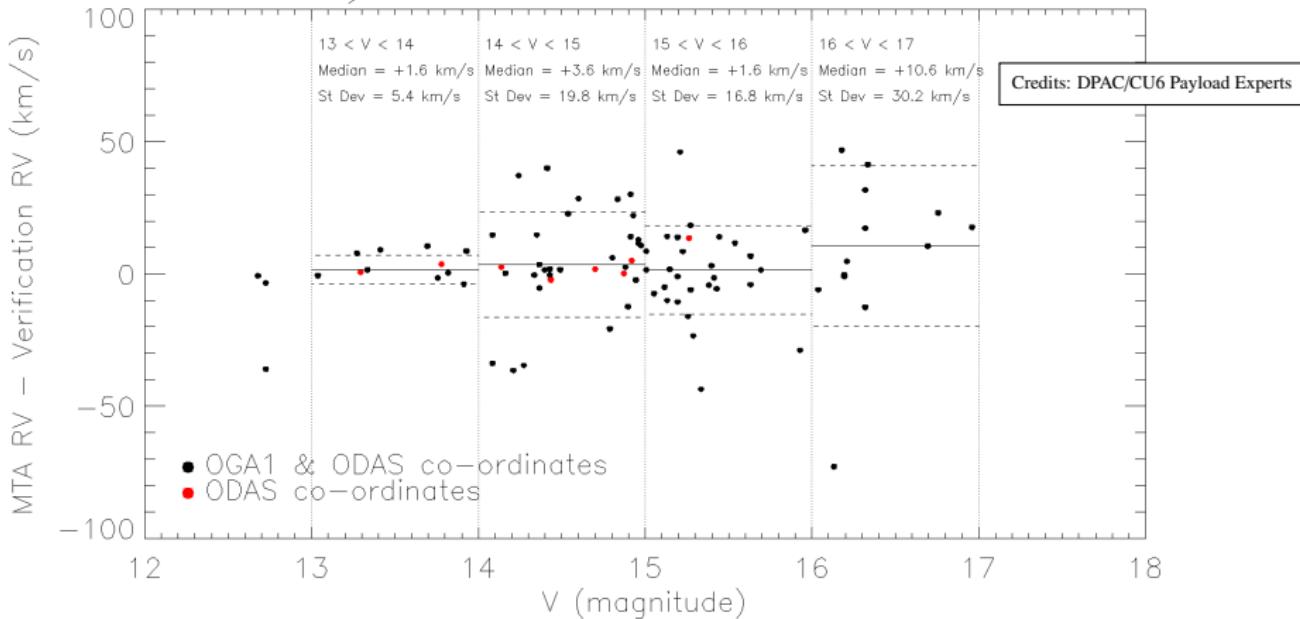
854 Ground-Based Standard (GBS) transits



- Bright end performance assessed by comparing RVS velocities to the known values for ground based standards
  - ▶ RVS values refer to single transits

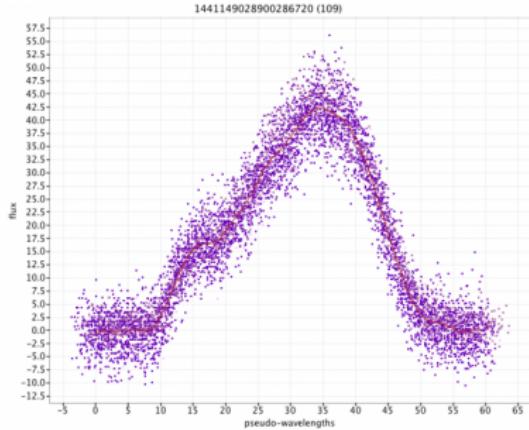
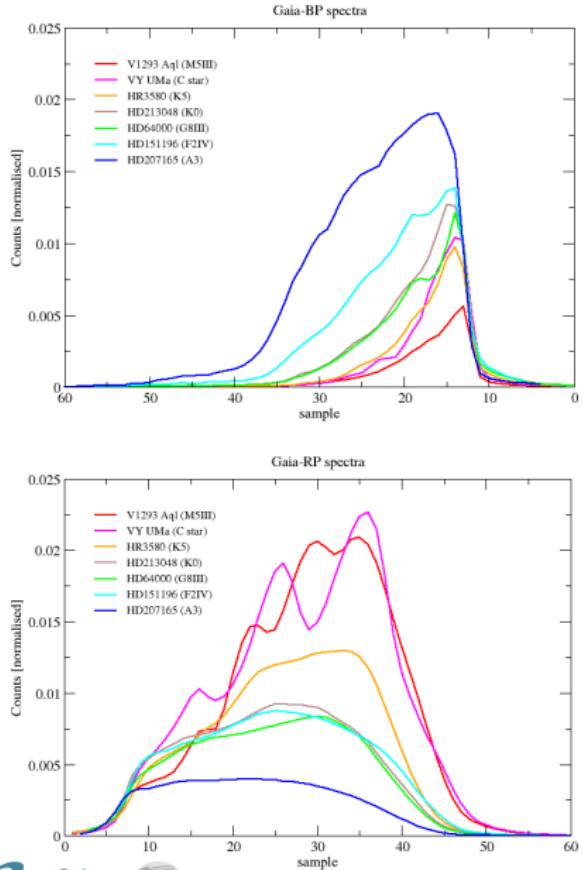
# Preliminary RVS performance assessment

28 days EPSL, 140 sources with 40 transits



- Performance assessment at faint end limited by intermediate astrometry accuracy

# Preliminary photometric performance assessment



Example of aligned and stacked RP spectra for a faint ( $G = 18.2$ ) star (DPAC/CU5)

Figures courtesy C. Jordi & J.-M. Carrasco

# Preliminary photometric performance assessment

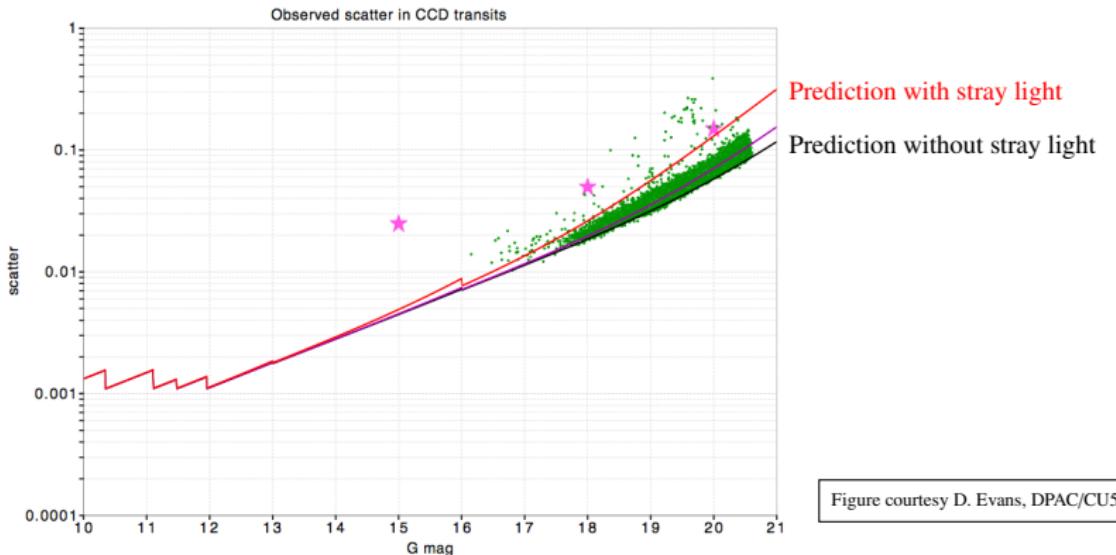
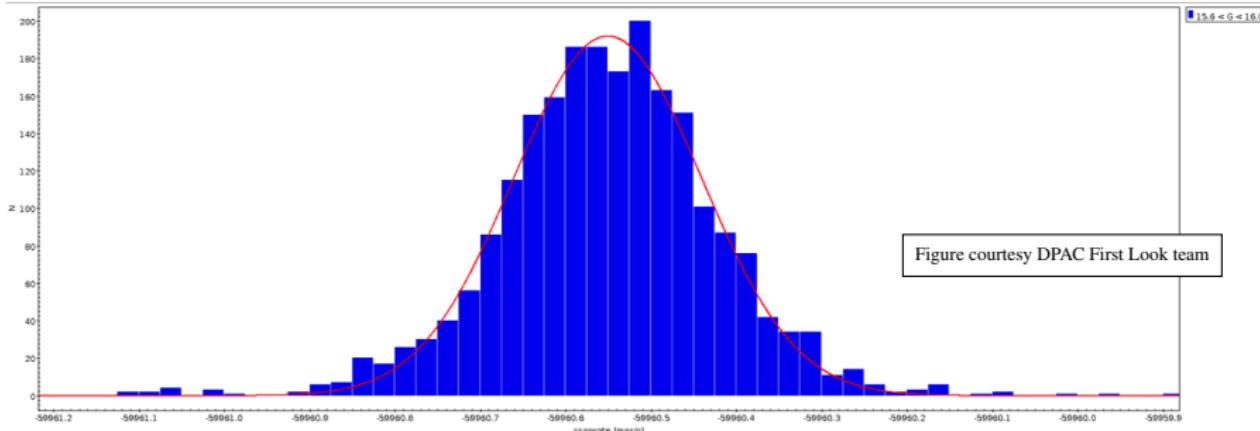


Figure courtesy D. Evans, DPAC/CU5

- Precision estimated from scatter of CCD transits of constant sources
- Lines: predictions from Jordi et al. 2010 methodology
  - ▶ Different stray light levels accounted for
- Quoted performances (magenta stars) from Gaia webpage are high
- End of mission equivalent for the mean photometry will be 25× smaller than CCD transit level accuracies
  - ▶ Limited by a calibration floor
- Early results — not all calibrations applied yet

# Astrometric data processing one year into the mission



- First runs of core astrometric solution (AGIS) completed
- Early indication of performance; analysis of CCD-to-CCD transit time differences (figure above) point to single CCD measurement precision of 0.38 mas at  $G = 15.8$ 
  - ▶ 17 per cent above target
- Caveats at this stage
  - ▶ poor PSF calibrations, no source colours
  - ▶ imperfect stray light corrections

# The Tycho-Gaia Astrometric Solution (TGAS)

- Trial runs with real data had started soon after the start of the nominal mission to ‘expose’ AGIS to flight data for technical interface checks, etc.
- No scientific value in these early runs
  - ▶ no good attitude solution
  - ▶ can only solve for source positions
- Disentangling parallax and proper motion needs more than 1 yr of data
- But wanted to experiment with full 5-parameter solutions as soon as possible
- TGAS idea
  - ▶ Identify HIP+Tycho-2 stars among the Gaia stars and add their positions at 1991 (from the HIP+Tycho-2 catalogues) as additional observations
  - ▶ Solution then possible with less than 1 yr of Gaia data
  - ▶ Proper motions and parallaxes for all 2.5 million stars
- See Michalik et al. (arXiv:1412.8770) for details
- Following slides courtesy Gaia AGIS Team

# The Tycho-Gaia Astrometric Solution (TGAS)

Gaia observations over 5 yr  $\Rightarrow$  position, parallax, proper motion

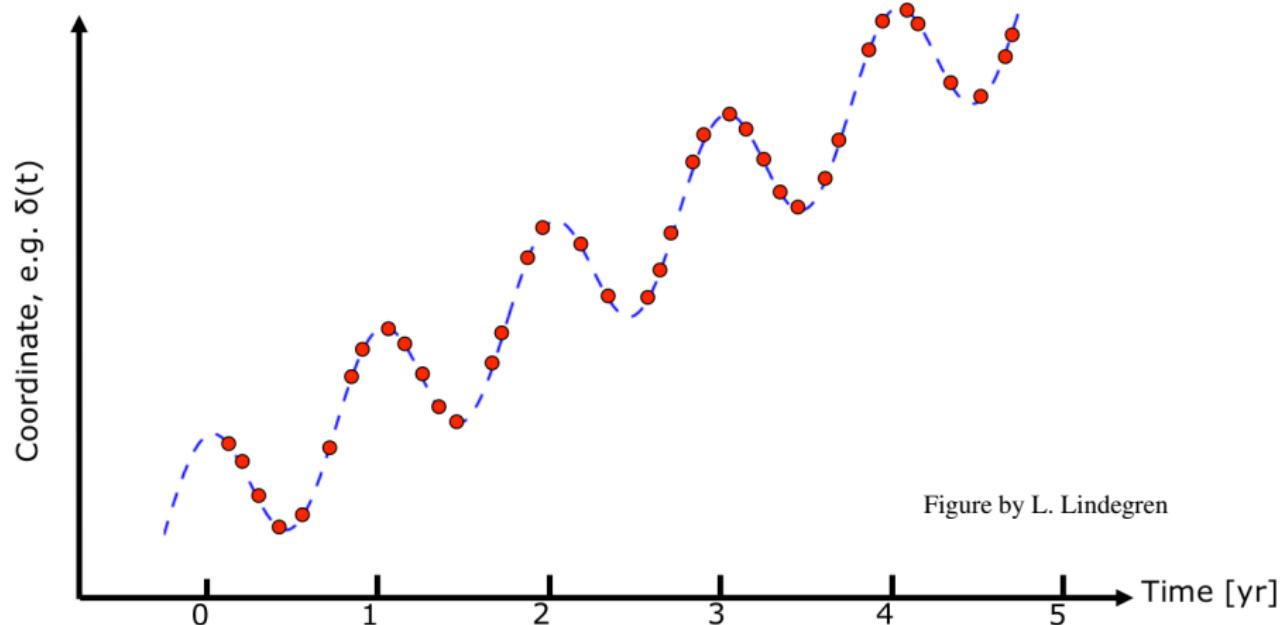
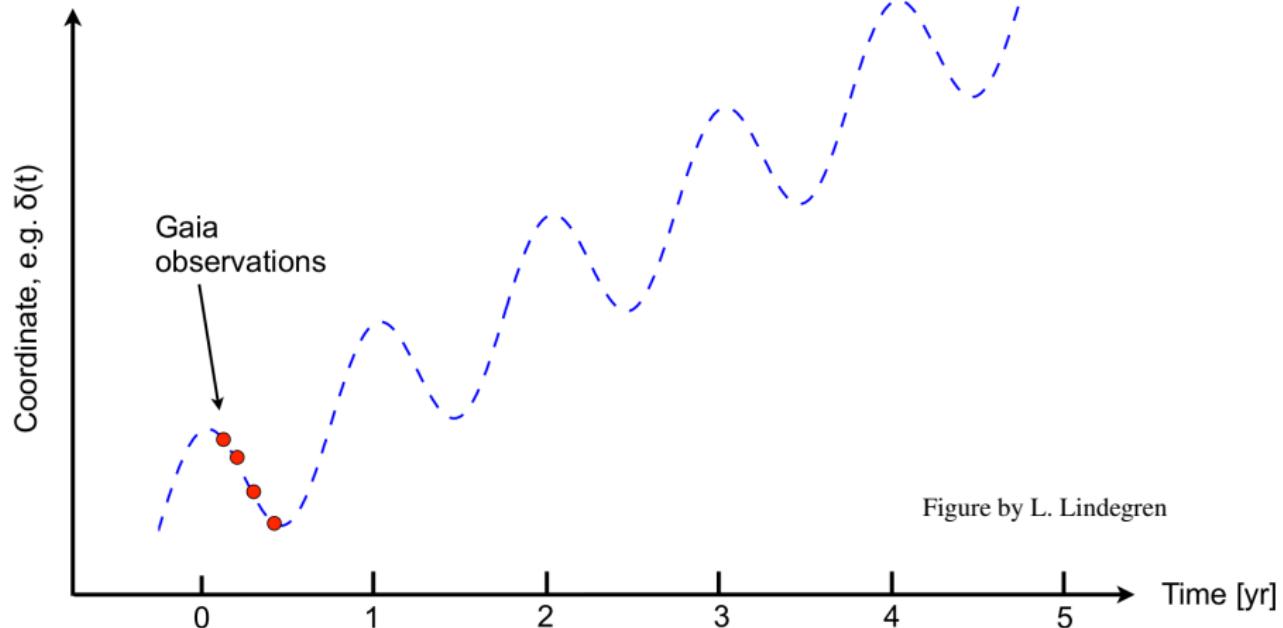


Figure by L. Lindegren

# The Tycho-Gaia Astrometric Solution (TGAS)

$\varpi - \mu$  degeneracy for < 1 year of observations



# The Tycho-Gaia Astrometric Solution (TGAS)

## TGAS (Tycho-Gaia Astrometric Solution): lifting the degeneracy

- Data used: ~ 275 days over 10 months
- 2 201 246 sources
  - ▶ Hipparcos: 99 070
  - ▶ Tycho-2 only: 2 102 176
- No. of CCD observations: 227 219 102 (most both AL and AC)
- Hipparcos proper motions and positions and Tycho-2 positions as priors
- *No Hipparcos parallaxes used*
- Empirical corrections for basic angle variations

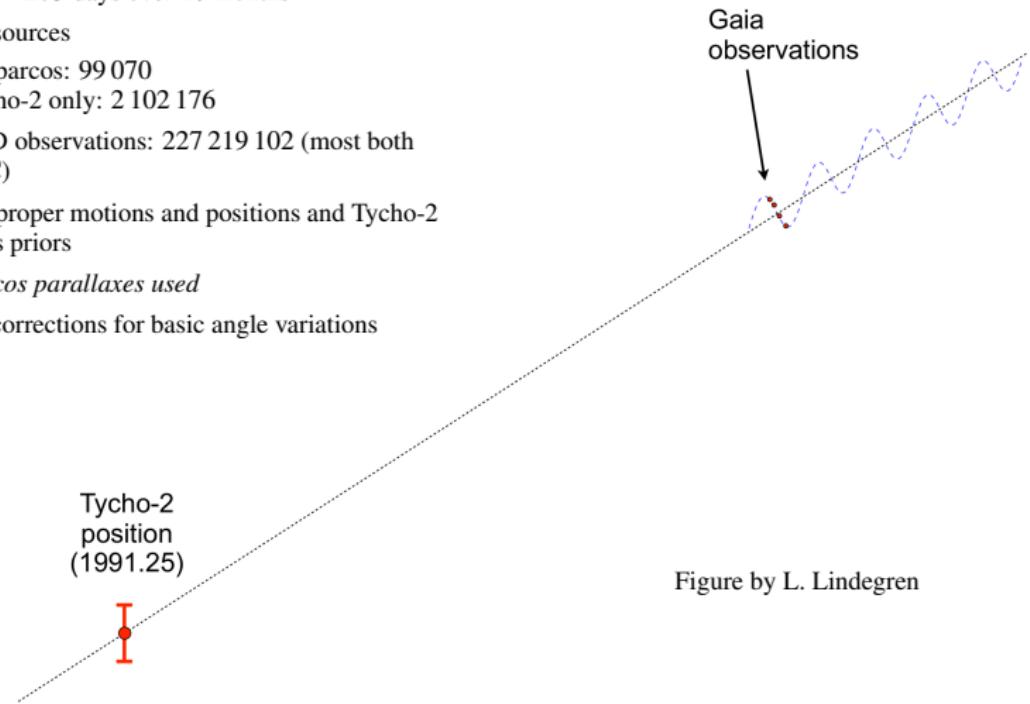
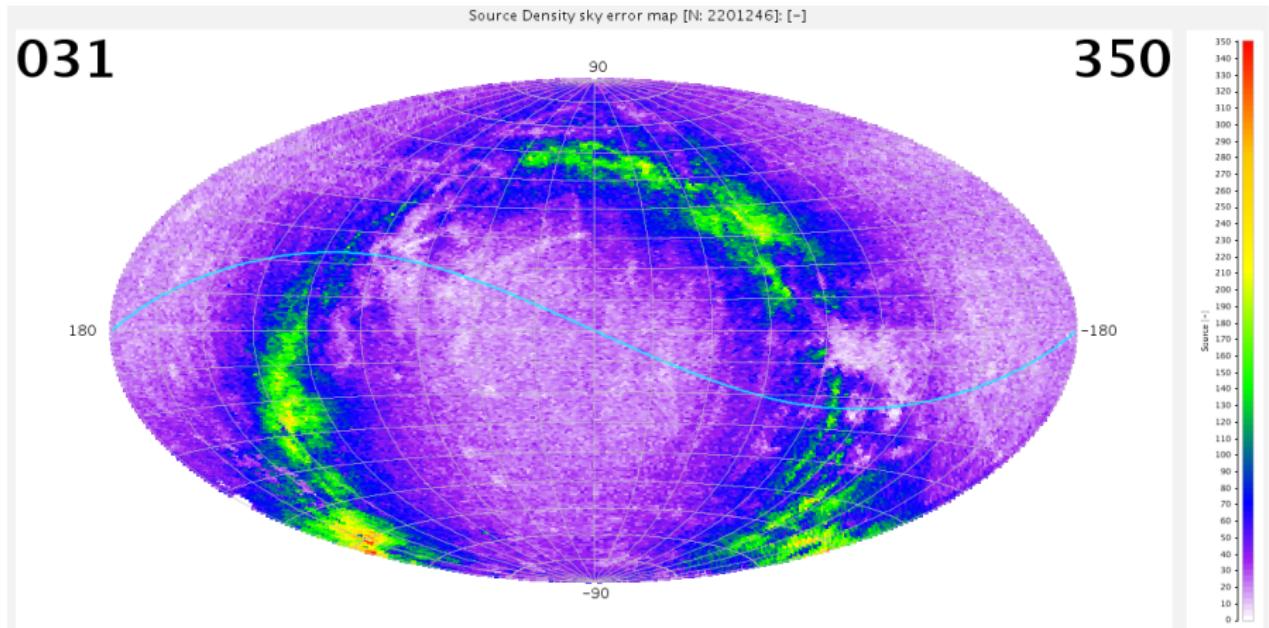


Figure by L. Lindegren

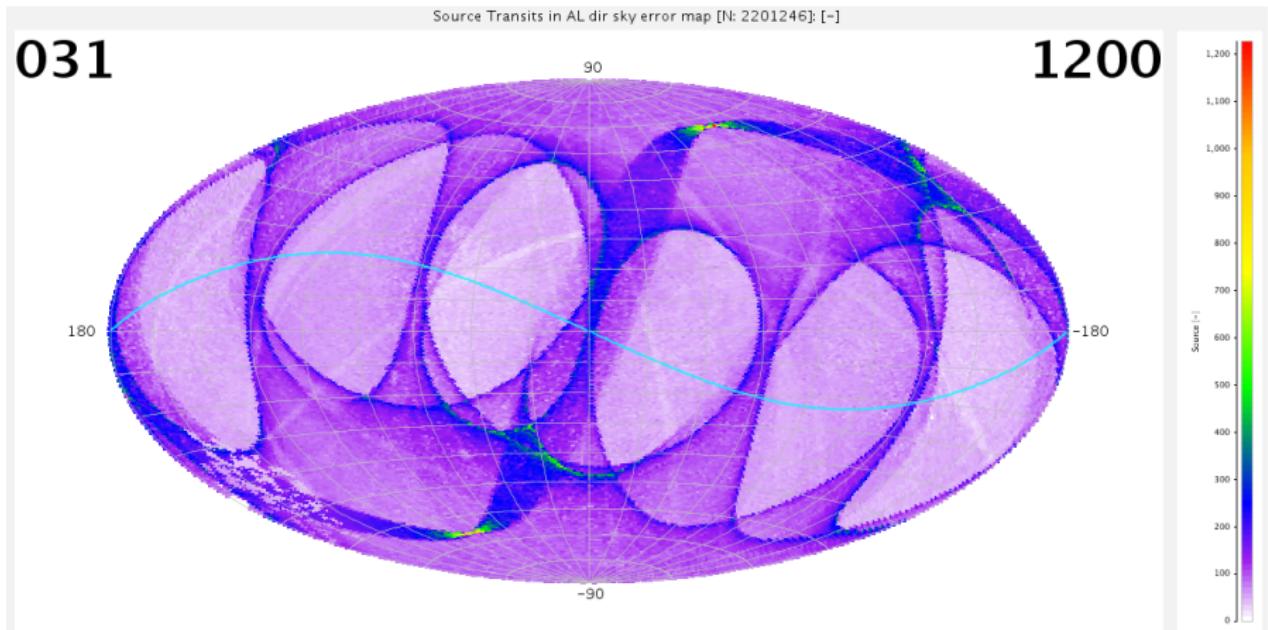
# The Tycho-Gaia Astrometric Solution (TGAS)

## Source distribution in position



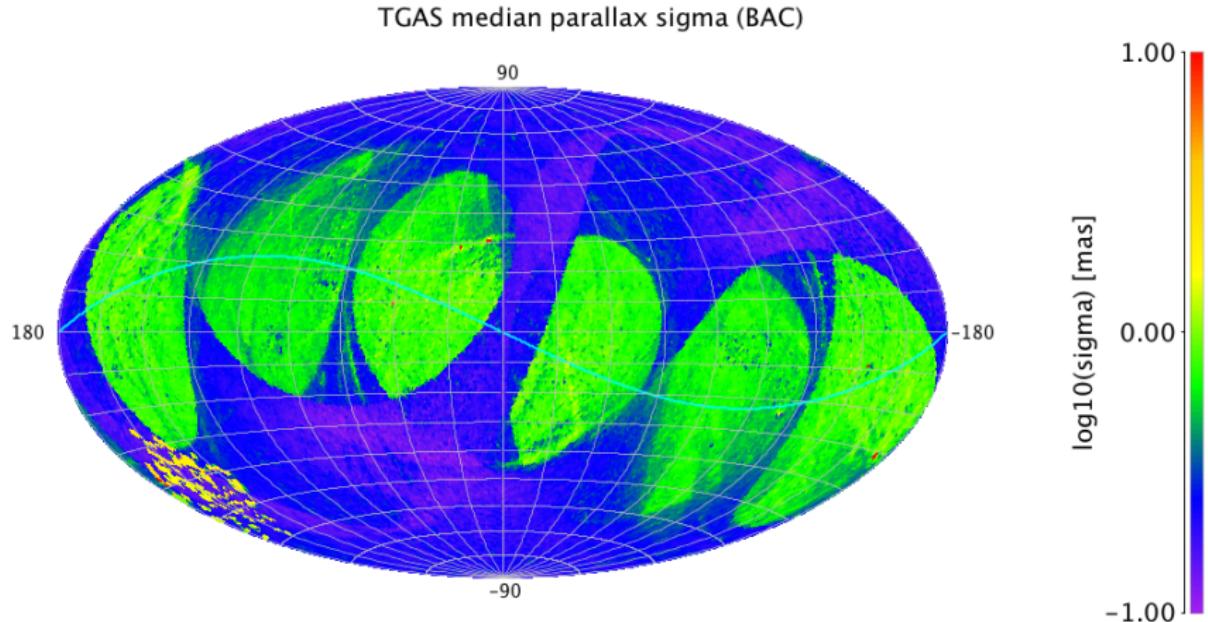
# The Tycho-Gaia Astrometric Solution (TGAS)

## Observation distribution (AL)



# The Tycho-Gaia Astrometric Solution (TGAS)

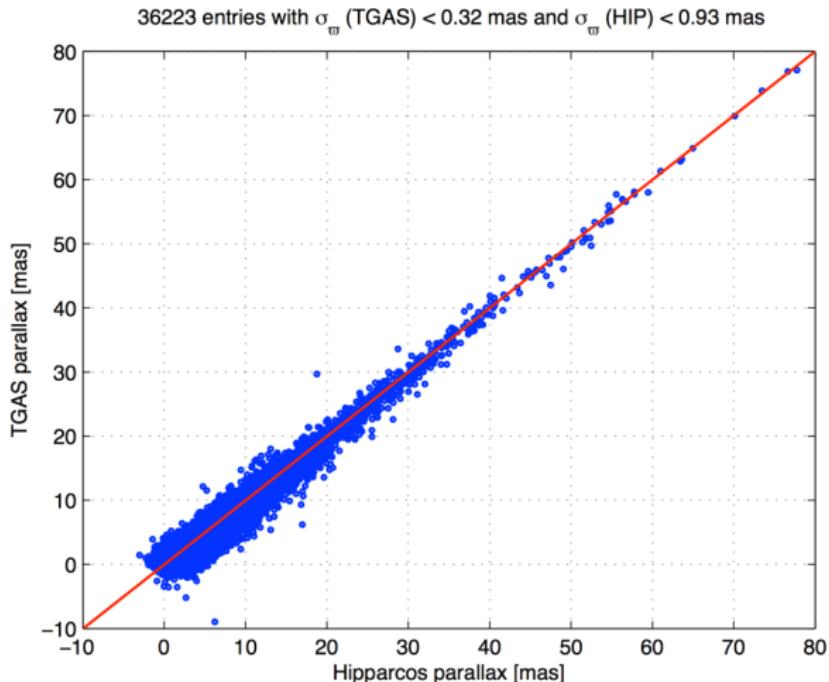
## Parallax formal standard uncertainties



Inspection of parallax distributions (negative tails) shows that  $\sigma_{\pi}$  values are meaningful but require empirical adjustment.

# The Tycho-Gaia Astrometric Solution (TGAS)

$\varpi_{\text{TGAS}}$  VS.  $\varpi_{\text{HIP}}$

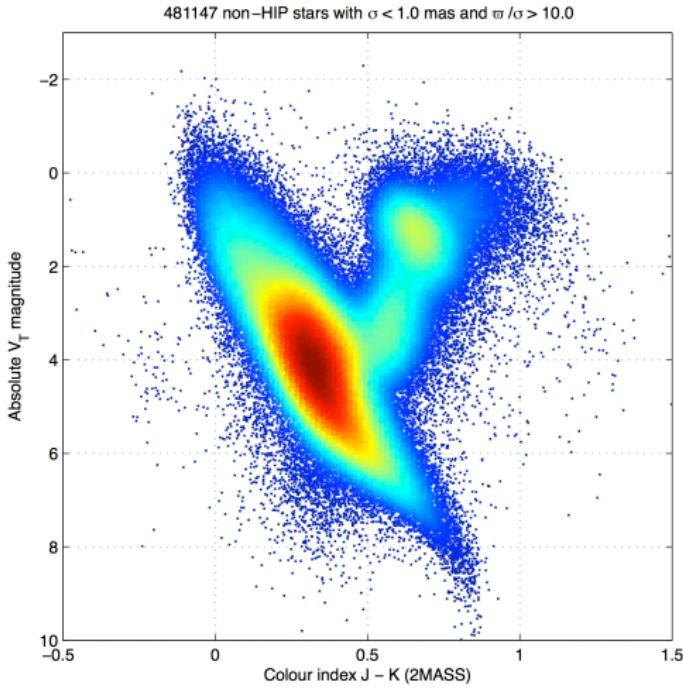


NOTE: TGAS parallaxes are independent of HIP parallaxes!

# The Tycho-Gaia Astrometric Solution (TGAS)

HR diagram for non-Hipparcos subset

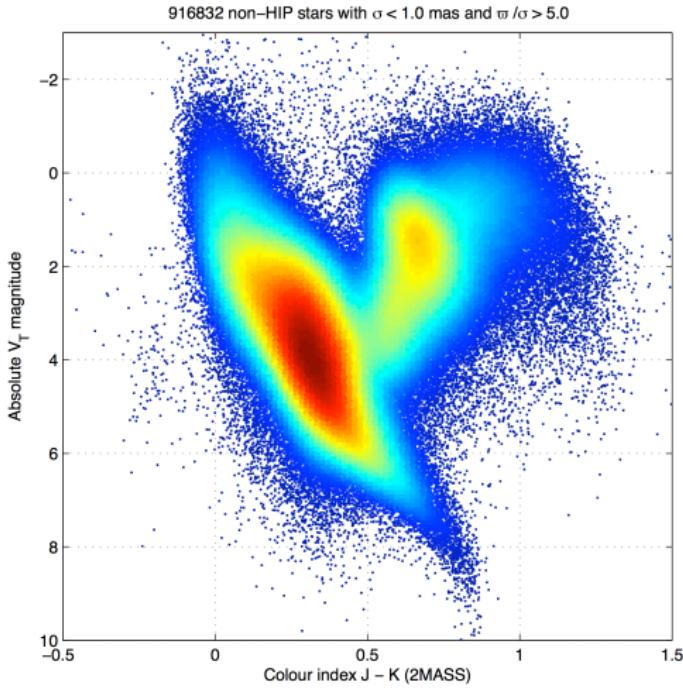
(481 147 stars with 2MASS colours,  $\varpi > 0$ ,  $\sigma_\varpi < 1$  mas,  $\varpi/\sigma_\varpi > 10$ )



# The Tycho-Gaia Astrometric Solution (TGAS)

HR diagram for non-Hipparcos subset

(961 832 stars with 2MASS colours,  $\varpi > 0$ ,  $\sigma_\varpi < 1$  mas,  $\varpi/\sigma_\varpi > 5$ )



Performance predictions for G2V star			
V magnitude	Astrometry (parallax)	Photometry (BP/RP integrated)	Spectroscopy (radial velocity)
3 to 12	5–14 $\mu$ as	4 mmag	
3 to 12.3			1 km s <sup>-1</sup>
15	24 $\mu$ as	4 mmag	
15.2			15 km s <sup>-1</sup>
20	540 $\mu$ as	60 (RP) – 80 (BP) mmag	

Calculations by: Airbus DS, D. Katz, C. Jordi, L. Lindegren, J. de Bruijne

Up-to-date information always at:

<http://www.cosmos.esa.int/web/gaia/science-performance>

- Based on assumption of smooth development and operations!
- Each release updates the previous and contains significant new additions
- Science alerts started already

Mid-2016 Positions +  $G$  magnitude ( $\sim$  all sky, single stars)

- Includes more often scanned Ecliptic pole regions
- Hundred Thousand Proper Motions (Hipparcos-Gaia,  $\sim 50 \mu\text{as/yr}$ )

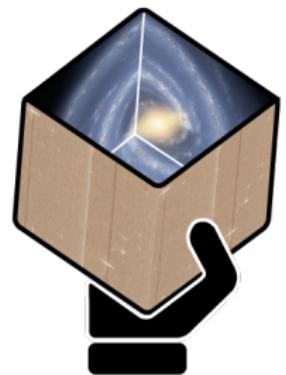
Early 2017 radial velocities for bright stars, two-band photometry, and full astrometry ( $\alpha, \delta, \varpi, \mu_{\alpha*}, \mu_\delta$ ) where available.

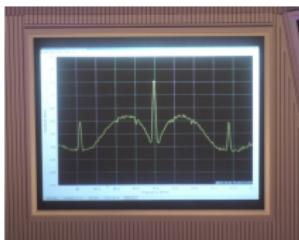
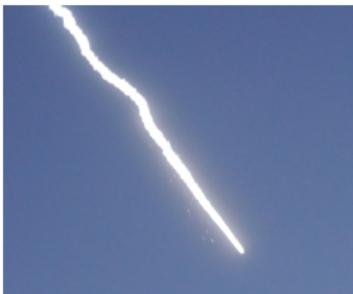
2017/2018 (TBC) full astrometry, orbital solutions for short period binaries,  $(G_{\text{BP}} - G_{\text{RP}})$ , BP/RP Spectrophotometry and astrophysical parameters , radial velocities, RVS spectra

2018/2019 (TBC) Updates on previous release — including more sources, source classifications, multiple astrophysical parameters, variable star solutions and epoch photometry for them, solar system results

2022 (TBC) Everything

- No proprietary period for DPAC (or ESA member states)
- Main archive hosted at ESAC
- Partner data centres: CDS Strasbourg, ASDC Rome, ARI Heidelberg, AIP Potsdam
- Outside Europe: USNO, STScI, SAAO
- DPAC CU9 dedicated to catalogue and archive publication
  - ▶ data validation
  - ▶ documentation
  - ▶ science exploitation tools (data mining, visualization, etc)
  - ▶ API for advanced access and use
  - ▶ outreach
- Your ideas and suggestions welcome
  - ▶ <http://great.ast.cam.ac.uk/Greatwiki/GaiaDataAccess>





SPACECRAFT	DATE	LAUNCHER
HERSCHEL	14 5 09	ARIANE 5
PLANCK	14 5 09	ARIANE 5
CRYOSAT-2	8 4 10	DNEPR
MSG-3	5 7 12	ARIANE 5
METOP-B	17 9 12	ARIANE 5
SWARM A-B-C	22 11 13	SOYUZ
GAIA	19 12 13	ROCKET