76. Gaia Data Release 3

TODAY, 13 JUNE 2022, marks the release of Gaia DR3, a very important milestone in the content and availability of the Gaia mission results.

In this summary, I will recall the context, and list some of the key statistics of this data release, otherwise simply referring to the relevant ESA Gaia www pages where `full details of DR3`, and much more supplementary information, is available.

GAIA WAS launched from Kourou, French Guiana, on 19 December 2013, and after a 6-month commissioning phase, started routine operations in July 2014.

Gaia continuously scans the sky following a specified scanning 'law', thus providing a fairly uniform scanning of the celestial sphere, as well as a progressively more robust 'separation' of the astrometric parameters (position, parallax, and proper motion) of each star. In simple terms, as more measurements are accumulated over time, the accuracy of these various quantities improves.

With its outstanding scientific results already clearly demonstrated, ESA's advisory committees approved the extension of mission operations beyond its original target of 5 years. If the operational lifetime is limited only by its cold gas propulsion system (responsible for driving the scanning law), Gaia can be expected to operate for around 10 years in total, to around 2023–24.

IN MY EARLIER essay #10 (8 March 2021) I gave a summary of the contents of the three previous data releases: DR1 of 14 September 2016, resulting from the first 14 months of satellite observations (Jul 2014–Sep 2015); DR2 of 25 April 2018, from the first 22 months of satellite observations (Jul 2014–May 2016); and EDR3 of 3 December 2020, from the first 34 months of satellite observations (Jul 2014–May 2017).

Data Release 3 combines, for the same stretch of time and the same set of observations as EDR3 (Early Data Release 3), the same primary data, i.e. with no new astrometry nor new photometric calibrations.

The importance of Data Release 3 are the many new data products, including non-single stars and solar system objects, inferred from these observations.

SO, PRECISELY as for EDR3, DR3 contains the following astrometric and photometric information:

five-parameter astrometric solution (α, δ, ϖ, μ_α, μ_δ) for 585 million sources, with a limiting magnitude of $G \approx 21$ and a bright limit of $G \approx 3$.

six-parameter astrometric solution for a further 882 million sources includes a 'pseudo-colour', for sources lacking high-quality colour information.

two-parameter astrometric solution for around 344 million additional sources.

G magnitudes for around 1.806 billion sources.

G_{BP} and G_{RP} magnitudes for around 1.542 billion and 1.555 billion sources, respectively.

celestial reference frame sources for about 1.614 million celestial reference frame sources (Gaia–CRF3).

cross-matches between Gaia EDR3, and Gaia DR2, Hipparcos-2, Tycho-2 + TDSC merged, 2MASS PSC (merged with 2MASX), SDSS DR13, Pan-STARRS1 DR1, SkyMapper DR1, GSC 2.3, APASS DR9, RAVE DR5, allWISE, and URAT-1.

THIS information (again, already available in EDR3) is summarised in the following table:

Gaia DR3	
Observations:	
– time period	Jul 2014–May 2017
– observations duration	34 months
– reference epoch	J2016.0
– catalogue release date	13 June 2022
Astrometry:	
– total number (3–21 mag)	1,811,709,771
– 5-parameter solutions	585,416,709
– 6-parameter solutions	882,328,109
– 2-parameter solutions	343,964,953
Photometry:	
– mean G magnitude	1,806,254,432
– mean G_{BP} photometry	1,542,033,472
– mean G_{RP} photometry	1,554,997,939
Radial velocities (4–13 mag)	7,209,831

WHAT IS spectacular about the new DR3 content is, for example, the radial velocity information, and the classification of variability, spectral types, non-single objects, quasars, and solar system object properties, as summarised in numerical terms below:

New results in Gaia DR3	
Sources with radial velocities	33 812 183
Sources with mean G_{RVS}-band magnitudes	32 232 187
Sources with rotational velocities	3 524 677
Mean BP/RP spectra	219 197 643
Mean RVS spectra	999 645
Variable-source analysis	10 509 536
Variability types (from machine learning)	24
Classified variables	9 976 881
Cepheids	15 021
compact companions	6 306
eclipsing binaries	2 184 477
long-period variables	1 720 588
microlensing events	363
planetary transits	214
RR Lyrae stars	271 779
short-timescale variables	471 679
solar-like rotational variables	474 026
upper-main-sequence oscillators	54 476
active galactic nuclei	872 228
Variable with radial-velocity time series	1 898
Sources with object classifications	1 590 760 469
Stars with emission-line classifications	57 511
Astrophysical parameters (BP/RP spectra)	470 759 263
Astrophysical parameters (unresolved binary)	348 711 151
Spectral types	217 982 837
Evolutionary parameters (mass and age)	128 611 111
Hot stars with spectroscopic parameters	2 382 015
Ultra-cool stars	94 158
Cool stars with activity index	1 349 499
H-alpha emission measurements	235 384 119
Astrophysical parameters from RVS spectra	5 591 594
Chemical abundances from RVS spectra	2 513 593
Diffuse interstellar band in RVS spectrum	472 584
Non-single (astrometric, eclipsing, etc.)	813 687
orbital astrometric solutions	169 227
orbital spectroscopic solutions	186 905
eclipsing binaries	87 073
QSO candidates	6 649 162
redshifts	6 375 063
host galaxy detected	64 498
host surface brightness profiles	15 867
Galaxy candidates	4 842 342
redshifts	1 367 153
surface brightness profiles	914 837
Solar system objects	158 152
epoch astrometry (CCD transits)	23 336 467
orbits	154 787
BP/RP reflectance spectra	60 518
planetary satellites	31
All-sky Galactic extinction (HEALPix levels)	6, 7, 8, and 9

THE NUMBERS are colossal, and some further details are given at the above-referenced ESA www site.

To give just a flavour, the data release includes object classification for 1.59 billion sources, i.e. the majority of the objects observed. And a wealth of astrophysical data has been distilled from the BP/RP spectra, notably astrophysical parameters ($T_{\rm eff}$, log g, [M/H], and reddening) for 470 million objects, Hα emission for 235 million stars, spectral types for 217 million stars, evolutionary parameters (mass and age) for 128 million, activity indices for 1.3 million cool stars, emission-line classification for 57 000 stars, and spectroscopic parameters for 2.3 million hot stars and 94 000 ultra-cool stars.

The 10 million variables, along with their associated 'epoch photometry', have been classified (by 'supervised machine learning') into 24 classes, amongst which are 363 microlensing events and 214 planetary transits.

Amongst the solar-system results for 158 000 sources (including 31 planetary satellites) are orbital solutions and individual epoch observations for 154 000 objects, along with mean BP/RP reflectance spectra for more than 60 000 objects.

There are 6.6 million quasar candidates, with redshift estimates for most. Amongst these, the host galaxies are detected for 60 000, and 15 000 of these even have estimated surface brightness profiles.

Other highlights are all-sky Galactic extinction maps at four different spatial resolutions (HEALPix levels 6, 7, 8, and 9), and the Gaia Andromeda Photometric Survey (GAPS), consisting of the photometric time series for all 1.2 million sources located within a 5.5-degree radius field centred on the Andromeda galaxy.

MORE THAN 30 papers in the journal *Astronomy & Astrophysics* are accompanying and detailing these Gaia DR3 data. Also listed are 10 'performance verification papers', which give an overview of the science potential of Gaia DR3, and an introduction to a few of the science topics that can be addressed with it.

Topics include mapping the Galaxy's asymmetric disk; pulsations in main-sequence OBAF stars; reflectance spectra of solar system bodies; the extragalactic content; chemical cartography of the Milky Way; a 'golden sample' of astrophysical parameters; and mapping the diffuse interstellar bands at 862 nm.

ALL THIS PROVIDES a stunning preview of the science that lies ahead, as researchers around the world start to delve deep into the Gaia treasure trove.

From my retirement armchair, I express again my huge admiration of the Gaia Data Processing and Analysis Consortium and its members, some 450 scientists across Europe, who are working together, and often under very great schedule pressures, to deliver this remarkable 21st century view of our Galaxy!