Gaia Exoplanet Survey: The (Start of the) Astrometry Revolution

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A colleague, and a friend...

...Dimitri
Gaia Discovery Space

Unbiased, magnitude-limited planet census of maybe $10^6$–$10^7$ stars

> $10^4$ NEW gas giants ($< 15 \, M_{\text{JUP}}$) around A through M dwarfs

Numbers might as much as triple for a 10-yr mission


Gaia will test the fine structure of GP parameters distributions and frequencies (including the GP/BD transition), and investigate their changes as a function of stellar mass, metallicity, age, and multiplicity with unprecedented resolution
- Maybe 50% of known companions accessible to Gaia for true mass estimation
- MOST exoplanets found by Gaia around bright stars good for RV follow-up
GP Occurrence vs $[\text{Fe/H}], M_*$

**Gaia: $10^4$ stars in a bin!**
**Today: $10^2$ stars in a bin!**

How do giant planet frequencies, masses, orbits depend on the host stars’ properties?

Johnson et al. 2010

Mortier, Santos, Sozzetti et al. 2012

Exoplanet science in the Gaia era (ssw 2022)  
Caltech, pasadena (USA), 27/07/2022
1) Unique exploration of the GP/BD transition region of companions to (1000?) young stars (<200 pc) in a regime of separations mostly inaccessible to DI
2) Systematic improvement of DI-detected companions via detection of astrometric accelerations: that's another great synergy!

Gaia and Young Stars

1) Unique exploration of the GP/BD transition region of companions to (1000?) young stars (<200 pc) in a regime of separations mostly inaccessible to DI
2) Systematic improvement of DI-detected companions via detection of astrometric accelerations: that’s another great synergy!
Gaia & UCD Planets

- Found so far only in microlensing events
- Gaia will see ~1000 UCDs of all ages, with sufficient astrometric sensitivity to giant planets within 2-3 AU
- A fundamental test of planet formation!

Gaia & Post-MS Stars

- Gaia might be sensitive to massive planet around thousands of bright White Dwarfs
- Gaia will perform THE observational test of theoretical predictions related to:
  A) post-MS planet evolution &
  B) 2nd generation planet formation

<table>
<thead>
<tr>
<th></th>
<th>D&lt;100 pc</th>
<th>D&lt;200 pc</th>
</tr>
</thead>
<tbody>
<tr>
<td>G&lt;13</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>G&lt;14</td>
<td>200</td>
<td>1600</td>
</tr>
<tr>
<td>G&lt;15</td>
<td>800</td>
<td>6400</td>
</tr>
</tbody>
</table>

Sozzetti 2014

Silvotti, Sozzetti et al. 2015
Gaia DR2 & EDR3:  
No direct binarity information  

...Any Exoplanet Science with DR2/EDR3?  

YES!
Calibration of the Hosts

Take Gaia parallaxes, and then do it your way!

Fulton & Petigura 2018

DR2/EDR3:
Bright (V<13) F-G-K stars (D<300-400 pc) and not very faint (V<16) M dwarfs (D<50-60 pc) have distances determined to 5%, or better

Derive 'accurate' stellar (and planetary) radii to within 5% or better
Much improved understanding of demographics (e.g., radius valley)

See D. Huber, O. Creevey's, J. Christiansen's talks
Constraints on Companions

Kervella et al. 2019, 2022

See P. Kervella’s, T. Brandt’s, M. Brandt’s talks

Proxima Centauri

Exoplanet science in the Gaia era (ssw 2022)

Caltech, pasadena (USA), 27/07/2022
Dynamical Masses

Snellen & Brown 2018

Young, luminous, directly-imaged companions

Dupuy et al. 2019
New Detections

Select accelerating stars for follow-up direct-imaging observations

Bonavita et al. 2022

Increasing efficiency of identification of wide-orbit substellar companions!
The $\pi$ Mensae System

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<table>
<thead>
<tr>
<th>Star name</th>
<th>Epoch</th>
<th>$\Delta \mu_\alpha$ (mas yr(^{-1}))</th>
<th>$\Delta \mu_\delta$ (mas yr(^{-1}))</th>
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</thead>
<tbody>
<tr>
<td>$\pi$ Men</td>
<td>Hipparcos</td>
<td>0.768 ± 0.398</td>
<td>0.404 ± 0.445</td>
</tr>
<tr>
<td>$\pi$ Men</td>
<td>Gaia</td>
<td>0.707 ± 0.246</td>
<td>-0.739 ± 0.263</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Jump parameter</th>
<th>Prior</th>
<th>Best-fit value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i_b$ [deg]</td>
<td>$U(0.0, 180.0)$</td>
<td>$47.9^{+1.1}_{-1.3}$</td>
</tr>
<tr>
<td>$\Omega_b$ [deg]</td>
<td>$U(0.0, 360.0)$</td>
<td>$104.1^{+0.6}_{-0.5}$</td>
</tr>
<tr>
<td>Mass, $m_b$ [M(_{\text{Jup}})] (derived)</td>
<td></td>
<td>$13.4^{+0.3}_{-0.2}$</td>
</tr>
</tbody>
</table>

$$\cos i_{\text{rel}} = \cos i_{\text{in}} \cos i_{\text{out}} + \sin i_{\text{in}} \sin i_{\text{out}} \cos (\Omega_{\text{out}} - \Omega_{\text{in}})$$

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**Damasso, Sozzetti et al. 2020**

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_c/R_\star$</td>
<td>$0.0165\pm 0.0001$</td>
</tr>
<tr>
<td>$a_c/R_\star$</td>
<td>$12.5\pm 0.3$</td>
</tr>
<tr>
<td>$i_c$ [deg]</td>
<td>$87.05\pm 0.15$</td>
</tr>
<tr>
<td>Eccentricity, $e_b$</td>
<td>$0.642\pm 0.001$</td>
</tr>
<tr>
<td>Argument of periastron, $\omega_{\star, b}$ [deg]</td>
<td>$-30.1\pm 0.3$</td>
</tr>
<tr>
<td>$T_b, \text{periastron}$ [BJD-2 450 000]</td>
<td>$8388.6\pm 2.2$</td>
</tr>
<tr>
<td>Minimum mass, $m_b \sin i_b$ [M(_{\text{Jup}})]</td>
<td>$9.89\pm 0.25$</td>
</tr>
<tr>
<td>Orbital semi-major axis, $a_b$ [au]</td>
<td>$3.28\pm 0.04$</td>
</tr>
<tr>
<td>Eccentricity, $e_c$ (fixed)</td>
<td>$0$</td>
</tr>
<tr>
<td>Argument of periastron, $\omega_{\star, c}$ [deg] (fixed)</td>
<td>$90$</td>
</tr>
<tr>
<td>Orbital semi-major axis, $a_c$ [au]</td>
<td>$0.0680\pm 0.0008$</td>
</tr>
<tr>
<td>Mass, $m_c$ [M(_{\odot})]</td>
<td>$4.3\pm 0.7$</td>
</tr>
<tr>
<td>Radius, $R_c$ [R(_{\odot})]</td>
<td>$2.11\pm 0.05$</td>
</tr>
<tr>
<td>Average density, $\rho_c$ [g cm(^{-3})]</td>
<td>$2.8\pm 0.5$</td>
</tr>
</tbody>
</table>
## Exoplanet science in the Gaia era

**DR3:**

**June 13th...**
Transiting Planets Update

Creevey et al. 2022

- A Golden Sample of sources with Gaia-based solid astrophysical parameters
- Transiting planets masses and radii are re-calibrated
Gaia Collaboration (Arenou) et al. 2022

<table>
<thead>
<tr>
<th>Table</th>
<th>Solution type</th>
<th>Solutions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>nss_acceleration_astro</td>
<td>Acceleration7</td>
<td>246,947</td>
<td>Second derivatives of position (acceleration)</td>
</tr>
<tr>
<td></td>
<td>Acceleration9</td>
<td>91,268</td>
<td>Third derivatives of position (jerk)</td>
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<tr>
<td>nss_two_body_orbit</td>
<td>Orbital</td>
<td>134,598</td>
<td>Orbital astrometric solutions</td>
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<tr>
<td></td>
<td>OrbitalAlternative*</td>
<td>629</td>
<td>Orbital astrometric, alternative solutions</td>
</tr>
<tr>
<td></td>
<td>OrbitalTargetedSearch*</td>
<td>533</td>
<td>Orbital astrometric, supplementary external input list</td>
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<td></td>
<td>AstroSpectroSB1</td>
<td>33,467</td>
<td>Combined orbital astrometric + spectroscopic solutions</td>
</tr>
<tr>
<td></td>
<td>SB1 or SB2</td>
<td>186,905</td>
<td>Orbital spectroscopic solutions</td>
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<tr>
<td></td>
<td>EclipsingSpectro</td>
<td>155</td>
<td>Combined orbital spectroscopic + eclipsing solutions</td>
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<tr>
<td></td>
<td>EclipsingBinary</td>
<td>86,918</td>
<td>Eclipsing binaries</td>
</tr>
<tr>
<td>nss_non_linear_spectro</td>
<td>FirstDegreeTrendSB1</td>
<td>24,083</td>
<td>First order derivatives of the radial velocity</td>
</tr>
<tr>
<td></td>
<td>SecondDegreeTrendSB1</td>
<td>32,725</td>
<td>Second order derivatives of the radial velocity</td>
</tr>
<tr>
<td>nss_vim_fl</td>
<td>VIMF</td>
<td>870</td>
<td>Variable-induced movers fixed</td>
</tr>
</tbody>
</table>

* Gaia identifies and characterizes orbiting companions through all its observing channels: Astrometry, Spectroscopy, and Photometry

* As a consequence, many solution types are published in DR3

* No information on multiplicity (> 1 companion) in DR3

See also processing papers: Halbwachs et al. 2022, Holl, Sozzetti et al. 2022, Gosset et al. 2022, Damerdji et al. 2022, Siopis et al. 2022 and on-line documentation: https://gea.esac.esa.int/archive/documentation/GDR3/index.html
* 45 times more spectroscopic orbits than in the SB9 Catalogue
* 300 times more astrometric binaries than in Orb6 Catalogue

Arenou et al. 2022
More Statistics

* Covering the entire HR diagram, including the White Dwarf sequence

Arenou et al. 2022

Exoplanet science in the Gaia era (ssw 2022)

Caltech, pasadena (USA), 27/07/2022
Some of the good...

Arenou et al. 2022
Some of the bad...

- Huge validation effort necessary

- (In)Completeness and biases characterization

- Bad solutions identification:
  Some removed, some still present

- Caveats and recommendations for bad solutions filtering
An Orrery of (Astrometric) Orbits

Credits: J. Sahlmann

Exoplanet science in the Gaia era (ssw 2022)
Substellar Companions

* Astrometry: 1843 BDs and 72 EPs candidates
- 10 BDs and 9 EPs already known
- Some literature EPs found to be BDs/LMS
- 13 BD-BD binaries, 7 already known

* Spectroscopy: 6K SB1 with $M_2 \sin(i) < 0.08 \, M_{\text{SUN}}$
- Many are probably aliases of longer periods
- 10 candidate Exoplanets
- One known transiting super-Jupiter correctly detected

* Photometry: > 200 transiting exoplanet candidates, some 70 new.

* Gaia candidate exoplanet list: https://www.cosmos.esa.int/web/gaia/exoplanets
* Gaia candidates now also in the Exoplanet Encyclopaedia: http://exoplanet.eu
Gaia DR3 astrometry: substellar mass companions

Credits: J. Sahlmann
Hosts of Substellar Companions

Primarily found around low-mass M dwarfs

Exoplanet science in the Gaia era (ssw 2022)

Caltech, pasadena (USA), 27/07/2022
BD Companion Occurrence

- Solar-type hosts of BDs have $<[\text{M/H}]> = -0.02 +/- 0.29$

- This value is right on estimates from RV surveys, with nearby field stars being more metal-poor, and planet hosts being more metal-rich

- Assuming 100% completeness and reliability, we infer for the first time a 0.3% occurrence rate of BDs around M dwarfs (likely underestimated, but it’s a first!)
Before you get too excited…

- Masses from $f(M)$:

$$\left( \frac{M_1 + M_2}{M_1 + M_2} \right) \left( \frac{M_2}{M_1 + M_2} - \frac{F_2/F_1}{1 + F_2/F_1} \right)^3 = \frac{(a_0/\bar{\omega})^3}{(P/365.25)^2}$$

- Small $f(M)$ -> Small $M_2$?

- Impostors: Binaries with $M_2/M_1 \approx F_2/F_1$

$f(M) < 0.001$

Arenou et al. 2022

Exoplanet science in the Gaia era (ssw 2022)

Caltech, pasadena (USA), 27/07/2022
An instructive case: HD 185501

Gaia orbit:
- $P = 450 \text{ d}$
- $a_1 = 480 \mu\text{as}$

As $d=32.7 \text{ pc}$, $M_s = 0.90 \ M_{\text{SUN}}$, $M_2$ could be a super-Jupiter or low-mass brown dwarf

Instead, it’s an equal-mass binary with the same period!

Horch et al. 2020

Exoplanet science in the Gaia era (ssw 2022)
‘OrbitalTargetedSearch’: Special Processing

- ≈20k sources with known solutions, including all exoplanets
- DE-MCMC and Genetic Algorithms for astrometric orbit determination
- Aim to probe the low astrometric SNR regime

Holl, Sozzetti et al. 2022
Orbit Fitting with Gaia  
(hands-on session)

Single-star Model (fully linear):

\[ w_{ss} = (\Delta \alpha^* + \mu_\alpha^* t) \sin \psi + (\Delta \delta + \mu_\delta t) \cos \psi + \sigma f_\sigma \]

NOTE: \( z \) is not used (known with much lower accuracy)

Keplerian Model (partly linear):

\[ w_{k1} = (B X + G Y) \sin \psi + (A X + F Y) \cos \psi \]

Linear component (Thiele-Innes elements):

- \( A = a_0 (\cos \omega \cos \Omega - \sin \omega \sin \Omega \cos i) \)
- \( B = a_0 (\cos \omega \sin \Omega + \sin \omega \cos \Omega \cos i) \)
- \( F = -a_0 (\sin \omega \cos \Omega + \cos \omega \sin \Omega \cos i) \)
- \( G = -a_0 (\sin \omega \sin \Omega - \cos \omega \cos \Omega \cos i) \)

Full model: \( w^{\text{model}} = w_{ss} + w_{k1} \)

Non-linear component:

\[ E - e \sin E = \frac{2\pi}{P} (t - T_0) \]
\[ X = \cos E - e \]
\[ Y = \sqrt{1 - e^2} \sin E \]

Figure of merit is the log-likelihood:

\[ -\ln (\mathcal{L}) = \frac{1}{2} \sum_{j=1}^{N_{asr}} \left( \frac{w_{j}^{\text{obs}} - w_{j}^{\text{(model)}}}{\sigma_{w,j}^2 + \sigma_{\text{jit}}^2} \right)^2 + \frac{1}{2} \sum_{j=1}^{N_{asr}} \ln \left( \sigma_{w,j}^2 + \sigma_{\text{jit}}^2 \right) \]
Orbits with Gaia: Finding the Period

Exoplanet science in the Gaia era (ssw 2022)
Verification: Internal checks (1)

Holl, Sozzetti et al. 2022
Verification: Internal checks (2)

Holl, Sozzetti et al. 2022

Exoplanet science in the Gaia era (ssw 2022)
Caltech, pasadena (USA), 27/07/2022
Validation: Gaia vs. Literature

Holl, Sozzetti et al. 2022

Exoplanet science in the Gaia era (ssw 2022)  Caltech, pasadena (USA), 27/07/2022
## Known Planets and BDs

Table 11. Known substellar companions with a confirmed mass in the planetary and brown dwarf regime, respectively.

<table>
<thead>
<tr>
<th>Gaia DR3</th>
<th>Name</th>
<th>$M_c \ sin \ t$ (M$_{Jup}$)</th>
<th>$M_c$ (M$_{Jup}$)</th>
<th>$t$ (deg)</th>
<th>$P_{lit}$ (days)</th>
<th>$P_{Gaia}$ (days)</th>
<th>$e_{lit}$</th>
<th>$e_{Gaia}$</th>
<th>$a_0$ (mas)</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6421118739093252224</td>
<td>HD 175167 b</td>
<td>7.8 ± 3.5</td>
<td>9.5 ± 0.9</td>
<td>28 ± 19</td>
<td>1290 ± 22</td>
<td>898 ± 198</td>
<td>0.54 ± 0.09</td>
<td>0.19 ± 0.12</td>
<td>0.22 ± 0.02</td>
<td>1</td>
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<tr>
<td>4062446910648807168</td>
<td>HD 164604 b</td>
<td>2.7 ± 1.3</td>
<td>14.3 ± 5.5</td>
<td>29 ± 19</td>
<td>606 ± 9</td>
<td>615 ± 12</td>
<td>0.24 ± 0.14</td>
<td>0.61 ± 0.34</td>
<td>0.56 ± 0.22</td>
<td>1.2</td>
</tr>
<tr>
<td>1594127865540229888</td>
<td>HD 132406 b</td>
<td>5.6</td>
<td>6.7 ± 2.1</td>
<td>122 ± 14</td>
<td>974 ± 39</td>
<td>893 ± 251</td>
<td>0.34 ± 0.09</td>
<td>0.31 ± 0.29</td>
<td>0.16 ± 0.04</td>
<td>3</td>
</tr>
<tr>
<td>474573313384418816</td>
<td>HR 810 b</td>
<td>2.26 ± 0.18</td>
<td>6.2 ± 0.5</td>
<td>87 ± 6</td>
<td>312 ± 5</td>
<td>332 ± 6</td>
<td>0.15 ± 0.05</td>
<td>0.04 ± 0.2</td>
<td>0.30 ± 0.02</td>
<td>4.5</td>
</tr>
<tr>
<td>2367734656180397592</td>
<td>BD -17 0063 b</td>
<td>5.1 ± 0.12</td>
<td>4.3 ± 0.5</td>
<td>80 ± 6</td>
<td>656 ± 0.6</td>
<td>649 ± 36</td>
<td>0.54 ± 0.005</td>
<td>0.28 ± 0.02</td>
<td>0.22 ± 0.02</td>
<td>6</td>
</tr>
<tr>
<td>585573058410531200</td>
<td>HD 11232 b</td>
<td>6.8</td>
<td>8.3 ± 0.6</td>
<td>97 ± 4</td>
<td>1143 ± 14</td>
<td>882 ± 34</td>
<td>0.20 ± 0.01</td>
<td>0.50 ± 0.10</td>
<td>0.51 ± 0.03</td>
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<tr>
<td>637329067475730368</td>
<td>HD 81040 b</td>
<td>6.8 ± 0.7</td>
<td>7.9 ± 0.9</td>
<td>108 ± 6</td>
<td>1002 ± 7</td>
<td>851 ± 113</td>
<td>0.53 ± 0.04</td>
<td>0.37 ± 0.15</td>
<td>0.39 ± 0.03</td>
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<tr>
<td>4976894960284258048</td>
<td>HD 142 b</td>
<td>1.3 ± 0.2</td>
<td>7.1 ± 1.0</td>
<td>59 ± 7</td>
<td>350 ± 4</td>
<td>319 ± 7</td>
<td>0.26 ± 0.18</td>
<td>0.26 ± 0.23</td>
<td>0.21 ± 0.03</td>
<td>5, 9, 10</td>
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<td>2603090003484152064</td>
<td>GJ 876 b</td>
<td>2.1 ± 0.2</td>
<td>3.6 ± 0.4</td>
<td>101 ± 8</td>
<td>61.08 ± 0.01</td>
<td>61.4 ± 0.2</td>
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<td>0.16 ± 0.15</td>
<td>0.43 ± 0.05</td>
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<tr>
<td>2651390587219807744</td>
<td>BD -00 4475 b</td>
<td>25 ± 2</td>
<td>48.4 ± 7.6</td>
<td>129 ± 7</td>
<td>723.2 ± 0.7</td>
<td>780 ± 84</td>
<td>0.39 ± 0.01</td>
<td>0.48 ± 0.11</td>
<td>1.91 ± 0.28</td>
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<tr>
<td>2778298280881817984</td>
<td>HD 5433 b</td>
<td>49 ± 3</td>
<td>53.8 ± 1.7</td>
<td>12 ± 39</td>
<td>576.6 ± 1.6</td>
<td>576.7 ± 10.6</td>
<td>0.81 ± 0.02</td>
<td>0.46 ± 0.12</td>
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<tr>
<td>3309006602007842048</td>
<td>HD 30246 b</td>
<td>55±40</td>
<td>40.6 ± 8.3</td>
<td>78 ± 2</td>
<td>990 ± 6</td>
<td>814 ± 141</td>
<td>0.84 ± 0.08</td>
<td>0.59 ± 0.10</td>
<td>1.34 ± 0.24</td>
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<tr>
<td>3755081083756665128</td>
<td>HD 91669 b</td>
<td>30.6 ± 2.1</td>
<td>43.2 ± 2.2</td>
<td>58 ± 3</td>
<td>497.0 ± 0.6</td>
<td>500.4 ± 6.9</td>
<td>0.448 ± 0.002</td>
<td>0.32 ± 0.06</td>
<td>0.73 ± 0.04</td>
<td>19</td>
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<tr>
<td>3755176367499617056</td>
<td>HD 89707 b</td>
<td>54±5</td>
<td>82.5 ± 12.7</td>
<td>54 ± 10</td>
<td>298.5 ± 0.1</td>
<td>297 ± 2</td>
<td>0.90 ± 0.04</td>
<td>0.68 ± 0.20</td>
<td>1.82 ± 0.30</td>
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<tr>
<td>68502955833355168</td>
<td>HD 77065 b</td>
<td>41 ± 2</td>
<td>64.2 ± 5.1</td>
<td>42 ± 3</td>
<td>119.11 ± 0.003</td>
<td>119.1 ± 0.2</td>
<td>0.694 ± 0.0004</td>
<td>0.70 ± 0.04</td>
<td>1.04 ± 0.07</td>
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<td>855523714036230016</td>
<td>HD 92320 b</td>
<td>59.4 ± 4.0</td>
<td>70 ± 3.1</td>
<td>111 ± 2</td>
<td>145.4 ± 0.01</td>
<td>145.1 ± 0.3</td>
<td>0.323 ± 0.001</td>
<td>0.26 ± 0.05</td>
<td>0.82 ± 0.01</td>
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</tr>
<tr>
<td>824461960796102528</td>
<td>HD 82460 b</td>
<td>73.2 ± 3.0</td>
<td>62.5 ± 6.4</td>
<td>66 ± 1</td>
<td>590.9 ± 0.2</td>
<td>579 ± 6</td>
<td>0.84 ± 0.01</td>
<td>0.73 ± 0.04</td>
<td>1.63 ± 0.09</td>
<td>21</td>
</tr>
<tr>
<td>87361680770228352</td>
<td>BD +29 1539 b</td>
<td>59.7 ± 2.0</td>
<td>60.7 ± 23.5</td>
<td>120 ± 9</td>
<td>175.87 ± 0.01</td>
<td>173 ± 3</td>
<td>0.275 ± 0.001</td>
<td>0.43 ± 0.12</td>
<td>0.61 ± 0.14</td>
<td>21</td>
</tr>
<tr>
<td>5563001178343925376</td>
<td>HD 52756 b</td>
<td>59.3 ± 2.0</td>
<td>61.2 ± 8.6</td>
<td>73 ± 4</td>
<td>52.8657 ± 0.0001</td>
<td>52.9 ± 0.1</td>
<td>0.678 ± 0.0003</td>
<td>0.54 ± 0.16</td>
<td>0.54 ± 0.08</td>
<td>22</td>
</tr>
</tbody>
</table>

References: (1) Arrigada et al. (2010); (2) Feng et al. (2019); (3) da Silva et al. (2007); (4) Kürster et al. (2000); (5) Butler et al. (2006); (6) Moutou et al. (2009); (7) Mayor et al. (2004); (8) Sozzetti et al. (2006); (9) Tinney et al. (2002); (10) Wittenmyer et al. (2012); (11) Trifonov et al. (2018); (12) Rivera et al. (2005); (13) Rivera et al. (2010); (14) Benedict et al. (2002); (15) Marcy et al. (1998); (16) Marcy et al. (2001); (17) Correia et al. (2010); (18) Nelson et al. (2016); (19) Dalal et al. (2021); (20) Wilson et al. (2016); (21) Kiefer et al. (2019); (22) Sahlmann et al. (2011).
High-mass Planets and BDs

- A dip in the distribution in the 20-40 MJUP regime (but small-number statistics)
- First-time investigation of the BD desert with true masses available!

Exoplanet science in the Gaia era (ssw 2022)

Caltech, pasadena (USA), 27/07/2022
Gaia transiting planets


First Gaia detections around moderately bright Sun-type stars:

Gaia-1b: P 3.05d, $M_p=1.78$ M$_J$, $R_p=1.23$ R$_J$
Gaia-2b: P 3.69d, $M_p=0.77$ M$_J$, $R_p=1.33$ R$_J
Gaia DR3 Astrometry: Known Exoplanets

**HD 81040 b:** known RV planet (Sozzetti et al. 2006)
Gaia DR3 confirms it’s a super-Jupiter

**GJ 876 b:**
A gas giant in a multiple system around an M dwarf at 4.7 pc (Marcy et al. 1998)
Gaia DR3 confirms its planetary nature

True masses for the first time!

Hands-on session!

Exoplanet science in the Gaia era (ssw 2022)
Caltech, pasadena (USA), 27/07/2022
A Famous Case

HD 114762 b:
- first substellar companion candidate around a solar-type star (Latham et al. 1989)
- Gaia DR3 orbit says it’s a low-mass star
Gaia DR3 Astrometry: New Exoplanet Candidates

A close-in super-Jupiter orbiting the nearby metal-polluted white dwarf WD 0141-675

Super-Jupiters around solar-type stars HIP 66074 and HIP 28193 and the young star HD 3221

First sample from Astrometry ever!
A(nother) Word of Caution

* G < 13 mag: typical $\sigma_A \sim 50-60$ $\mu$as
* DR3: systematic errors $\sim 0.15-0.2$ mas
* Calibration of bright stars still limited

Critical to improve significantly the bright-star performance:
- At G < 13 mag exoplanet detections maximize the Gaia impact and synergy potential
- At G > 13 mag exoplanet detections will primarily have only a statistical value
Forecasting for DR4 and DR5...

Gaia will test the fine structure of GP parameters distributions and frequencies (including the GP/BD transition), and investigate their changes as a function of stellar mass, metallicity, age, and multiplicity with unprecedented resolution.

No reason (yet) to doubt this will be the case!
SUMMARY

- Gaia DR2/EDR3 allowed to use a) parallaxes to improve accuracy and precision of stellar and planetary parameters, and b) proper motions in a clever way to improve knowledge of existing and find new substellar companions

- Gaia DR3 is wetting our appetite for exoplanet discoveries and is already a gold mine for BDs

- Not everything is hunky-dory, but we mostly know why

- We are beginning to work hard towards DR4

- The astrometry revolution has started!