

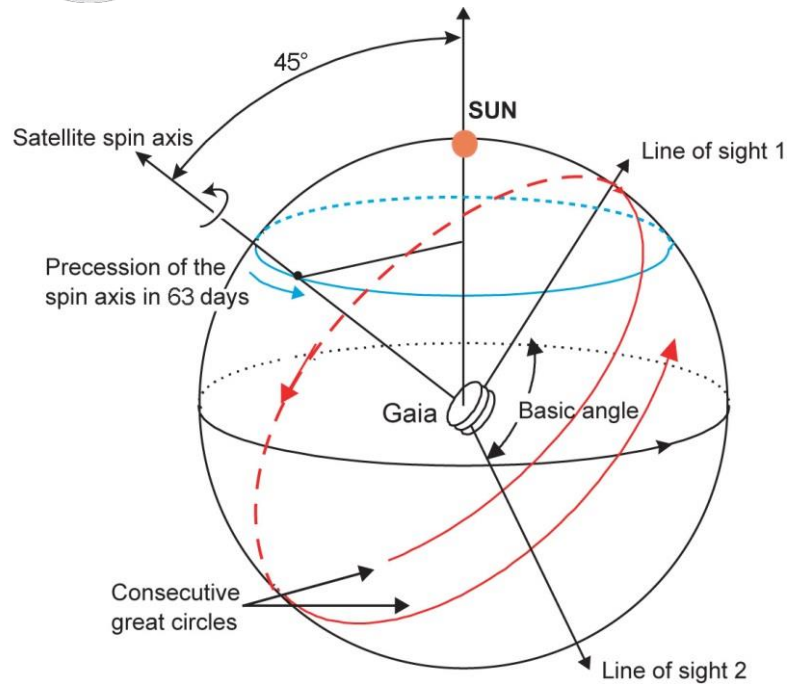
Gaia: Update + Exoplanet Science

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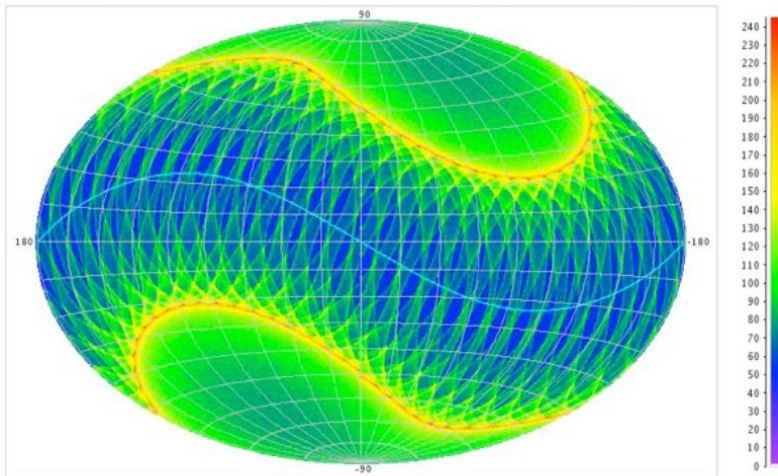


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A Space Astrometry Revolution!

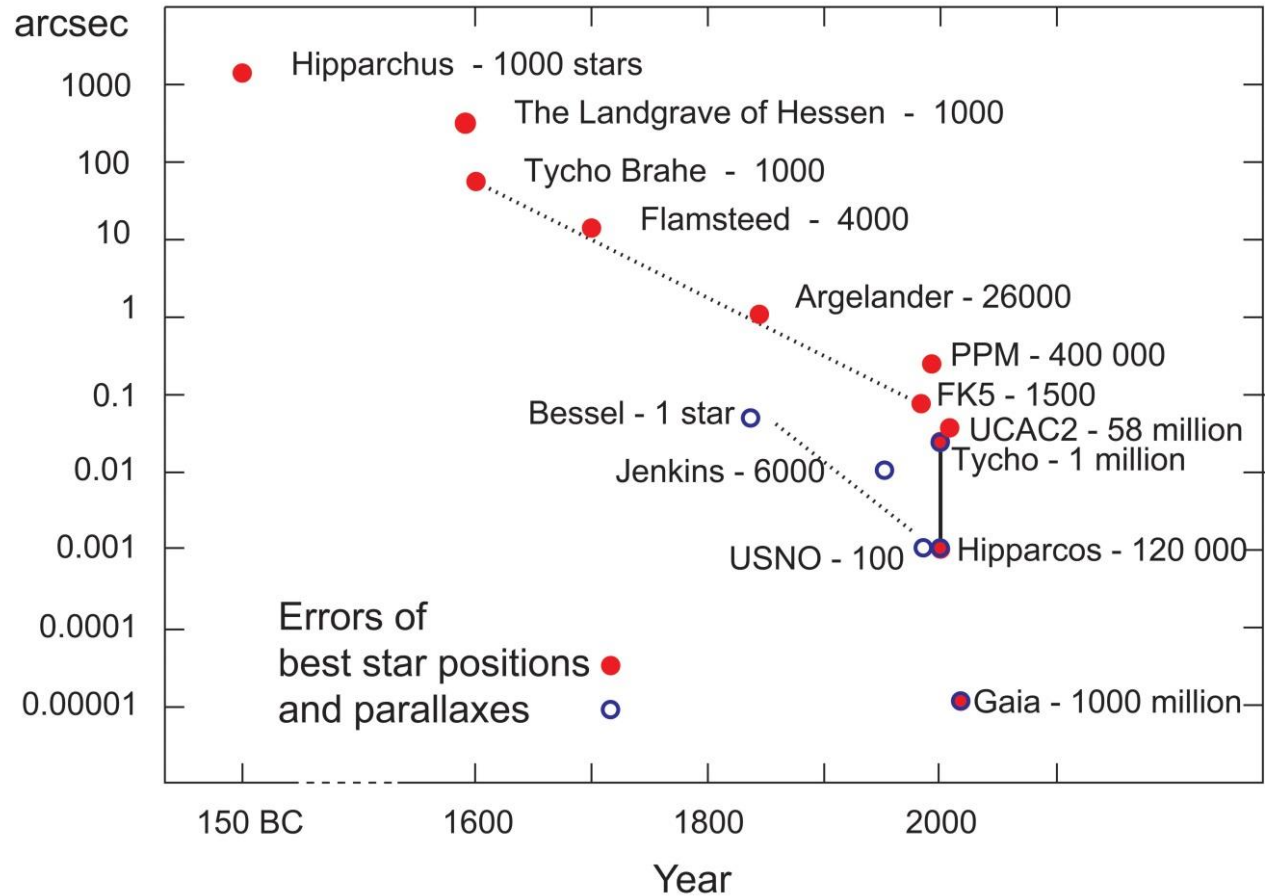


Number of FoV crossings per star (5 yr)



Equatorial projection

At Gaia's $G=20.7$ survey limit: 2×10^9 stars



μas astrometry comes of age...



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Gaia: Routine Operations

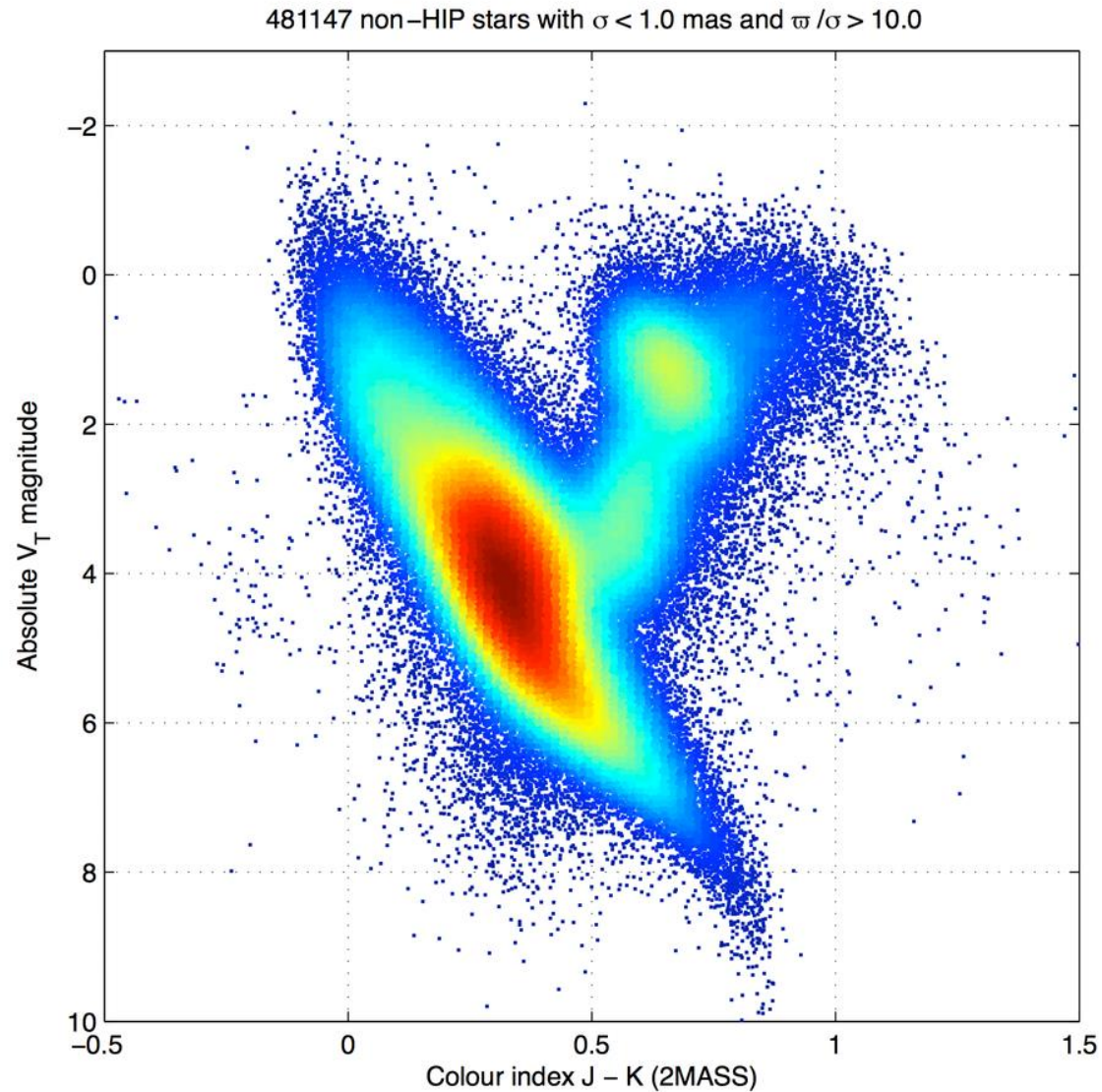


- In 5-year routine phase since 18 July 2014
- Nominal scanning law optimised for Jupiter quadrupole moment general relativity experiment
- Data collection:
 - 225 billion astrometric measurements
 - 45 billion photometric measurements
 - 4.4 billion spectra
- Magnitude limits
 - Astrometry and photometry between $2 < G < 20.7$ mag
 - Stars brighter than $G = 3$ mag captured with Sky Mapper imaging
 - Spectra till $G_{\text{RVS}} = 16.2$ mag (and $G > 2$ mag)



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TGAS Validation Run





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Unwanted Surprises

- Stray light both from astronomical sources and the Sun
 - Sun stray light due to scattering of fibres at the edge of the Sun shield
 - Impacts faint sources especially in spectroscopy
- Transmission loss due to continuing contamination of mirrors by water
 - Water source not yet exhausted although contamination rate much less than during commissioning
- Basic Angle variation larger than expected
 - Variation measured by on-board metrology device and verified at milliarsec level by astronomical sources
- Attitude disturbances
 - Micro-meteoroids taken into account in pre-launch work
 - At small impact levels many micro-clanks observed

Science Performance

Pre-launch predictions (Unreddened G2V star)

V-magnitude	Astrometry (parallax)	Photometry (BP/RP integrated)	Spectroscopy (radial velocity)
3 to 12	5-14 μ as	4 mmag	1 km/s
15	24 μ as	4 mmag	3 km/s
16.5			13 km/s
20	290 μ as	40 mmag	

Post-commissioning estimates

3 to 12	5-14 μ as	4 mmag	1 km/s
15	25 μ as	5 mmag	13 km/s
16.5			
20	540 μ as	60 (RP) – 80 (BP) mmag	

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



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Nominal Release Scenario



- 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 (α , δ , ϖ , $\mu_{\alpha*}$, μ_{δ}) 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



CU4 Team:

- INAF-OATo (Lead)
- U. Geneva
- IMCCE Paris



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Gaia Astrometry Planet Yield



**Starcounts ($V < 13$),
 $F_p(M_p, P)$ for F-G-K dwarfs,
Gaia completeness limit**

10^4 giants



Δd (pc)	N_\star	Δa (AU)	ΔM_p (M_J)	N_d	N_m
0-50	~10 000	1.0 - 4.0	1.0 - 13.0	~ 1400	~ 700
50-100	~51 000	1.0 - 4.0	1.5 - 13.0	~ 2500	~ 1750
100-150	~114 000	1.5 - 3.8	2.0 - 13.0	~ 2600	~ 1300
150-200	~295 000	1.4 - 3.4	3.0 - 13.0	~ 2150	~ 1050

Casertano, Lattanzi, Sozzetti et al. 2008

M dwarf starcounts ($G < 20$)



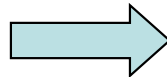
$2\text{--}3 \times 10^3$ additional giants (Sozzetti et al. 2014)

All spectral types ($G < 17.5$)



2×10^4 new gas giants (Perryman et al. 2014)

Close binaries within 200 pc



100s circumbinary giants (Sahlmann et al. 2014)

Unbiased, magnitude-limited planet census of possibly millions of stars

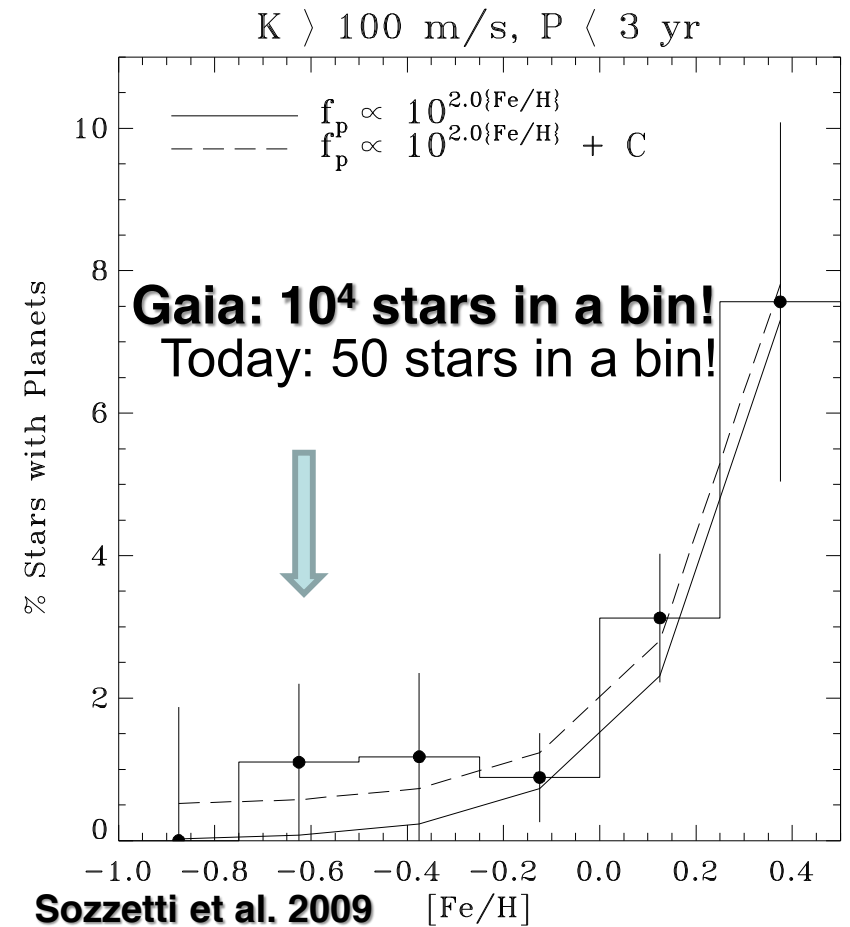
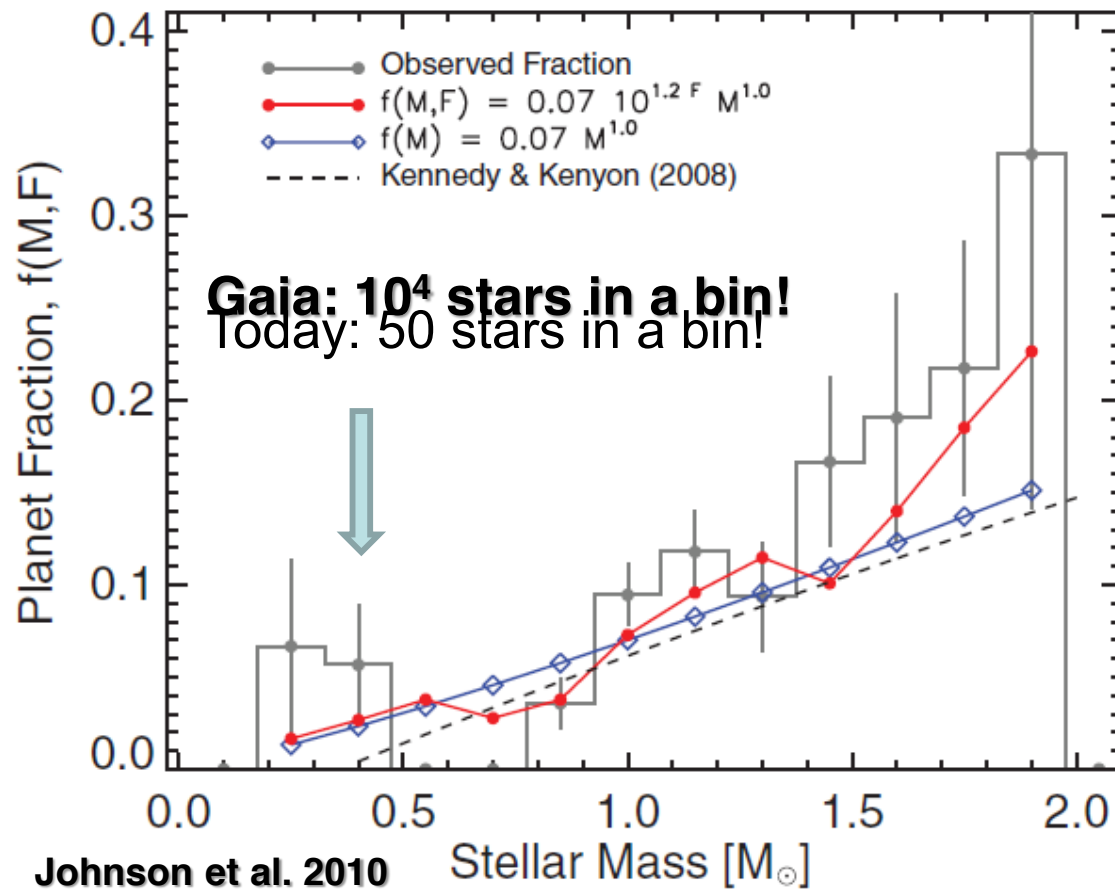
On the order of 10^4 NEW giant ($< 15 M_{JUP}$) planets

But, it must meet the noise floor requirements for bright stars!



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The Gaia Legacy

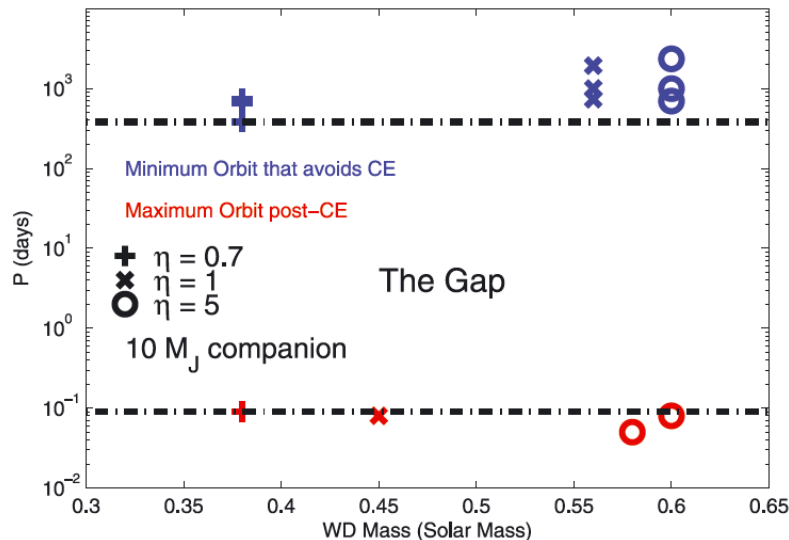
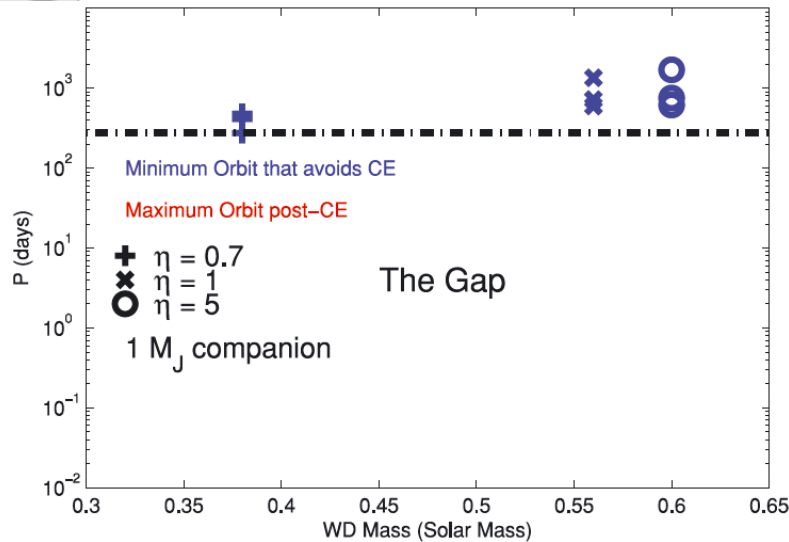


Gaia will test the fine structure of GP parameters distributions and frequencies (including the GP/BD transition), and investigate their changes as a function of stellar mass, metallicity, and age with unprecedented resolution



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Gaia & Post-MS Stars



White dwarfs in the solar neighborhood

Good to within a factor 2...

	D<100 pc	D<200 pc
R<13	50	400
R<14	200	1600
R<15	800	6400

Silvotti, Sozzetti, & Lattanzi, AIP

Gaia will perform THE observational test of theoretical predictions related to:
 A) post-MS planet evolution & B) 2nd generation planet formation

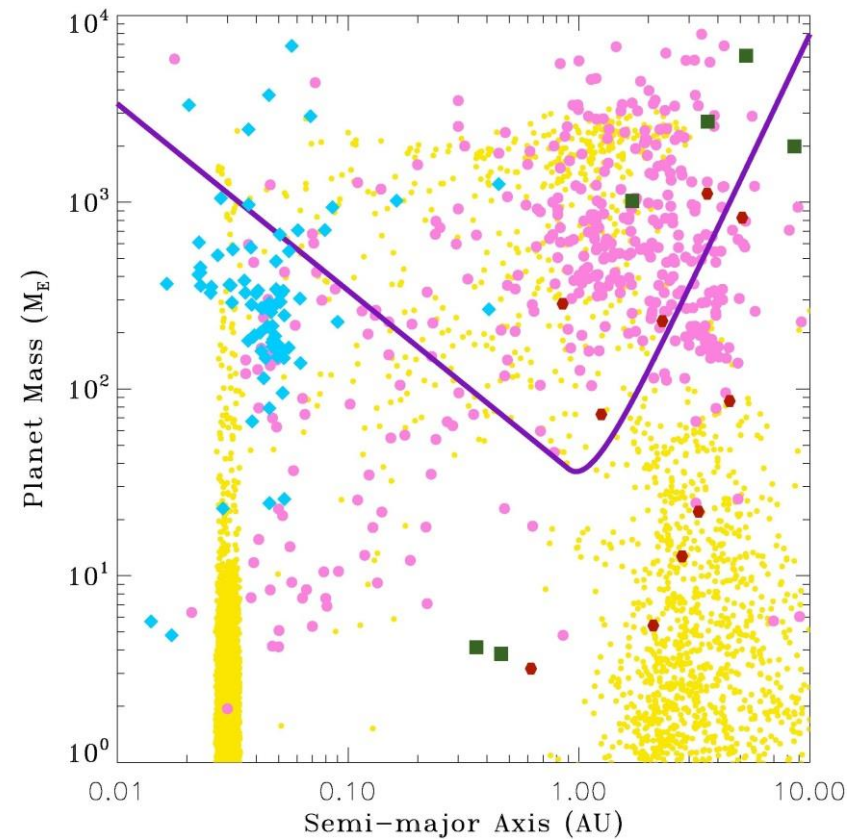
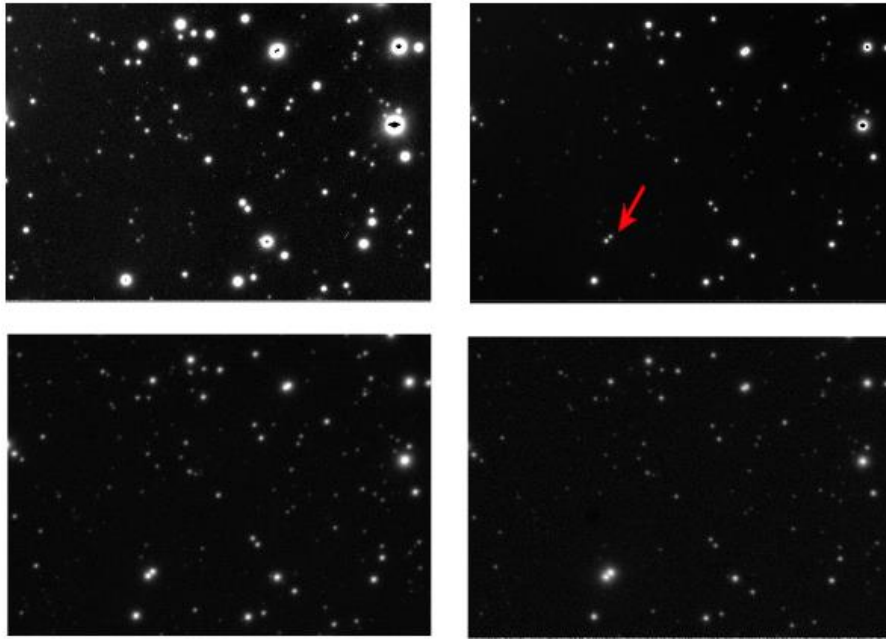


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Planets Around BDs



Gaia detection limits for Luhman 16 AB
(Boffin et al. 2014)



- Found so far only in microlensing events
- Gaia will see ~1000 BDs of all ages, with sufficient astrometric sensitivity to giant planets within 2-3 AU
- A fundamental test of planet formation! Sozzetti (arXiv:1406.1388)



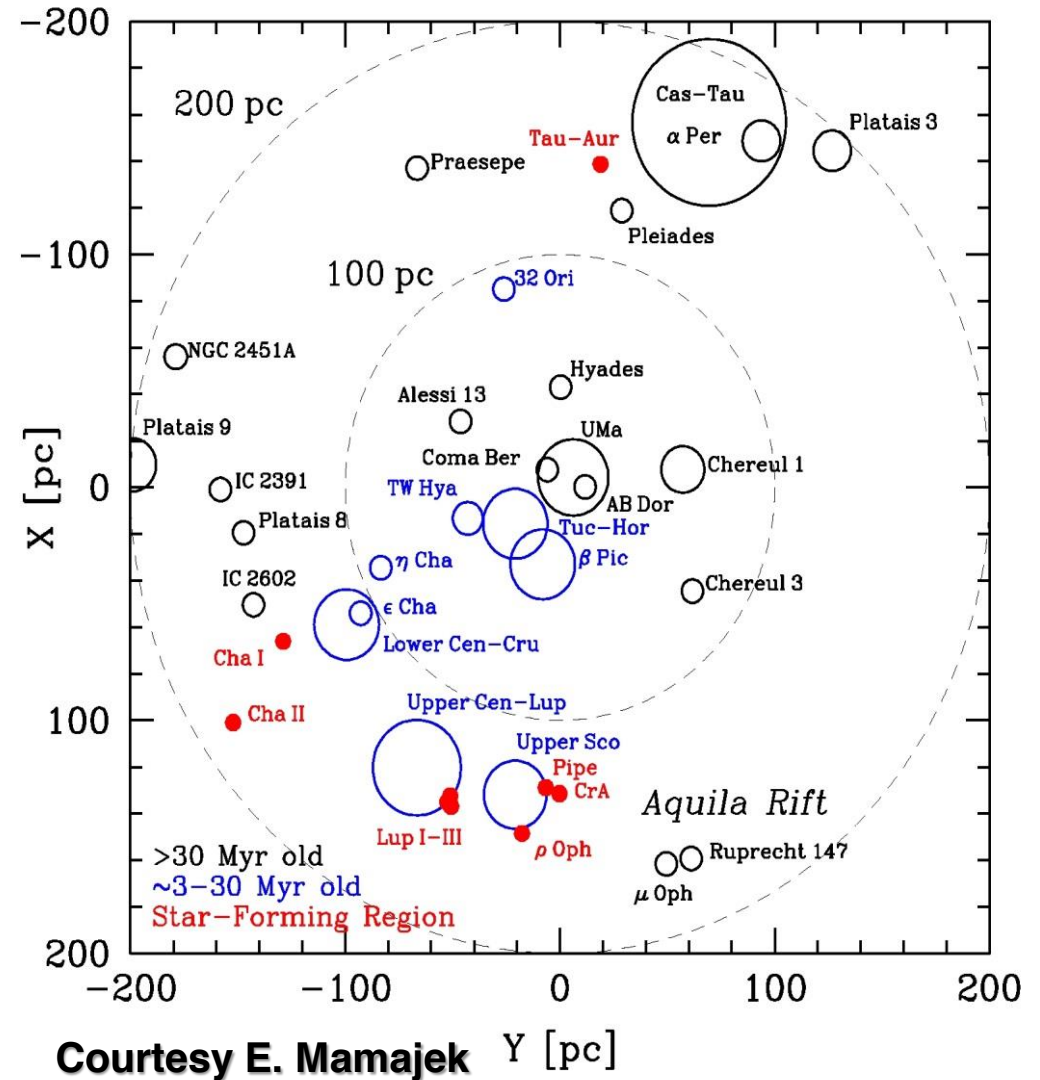
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Young Stars Near the Sun



Table 5. The closest (≤ 200 pc) star forming regions and young stellar kinematic groups. **Casertano, Lattanzi, Sozzetti et al. 2008**

Name	Distance (pc)	Age (Myr)
Hercules-Lyra	15–40	100
AB Doradus	20–50	30–50
Subgroup B4	20–50	80–100
β Pictoris	30–50	8–15
Tucana-Horologium	50–60	8–50
TW Hya	50	3–50
MBM 12	60–110	3–10
η Chamaeleontis	90–150	8–10
η Carinae	100	8
MBM 20	110–160	3–10
Pleiades	125	75–100
ϱ Ophiuchi	125–150	1–2
Taurus-Auriga	135	1–2
Corona Austrina	140	1–2
Lupus	140	1–2
σ Velorum	160	30
θ Carinae	160	30
Scorpio-Centaurus	160–180	2–20
α Persei	175	85
Serpens	200	5–10

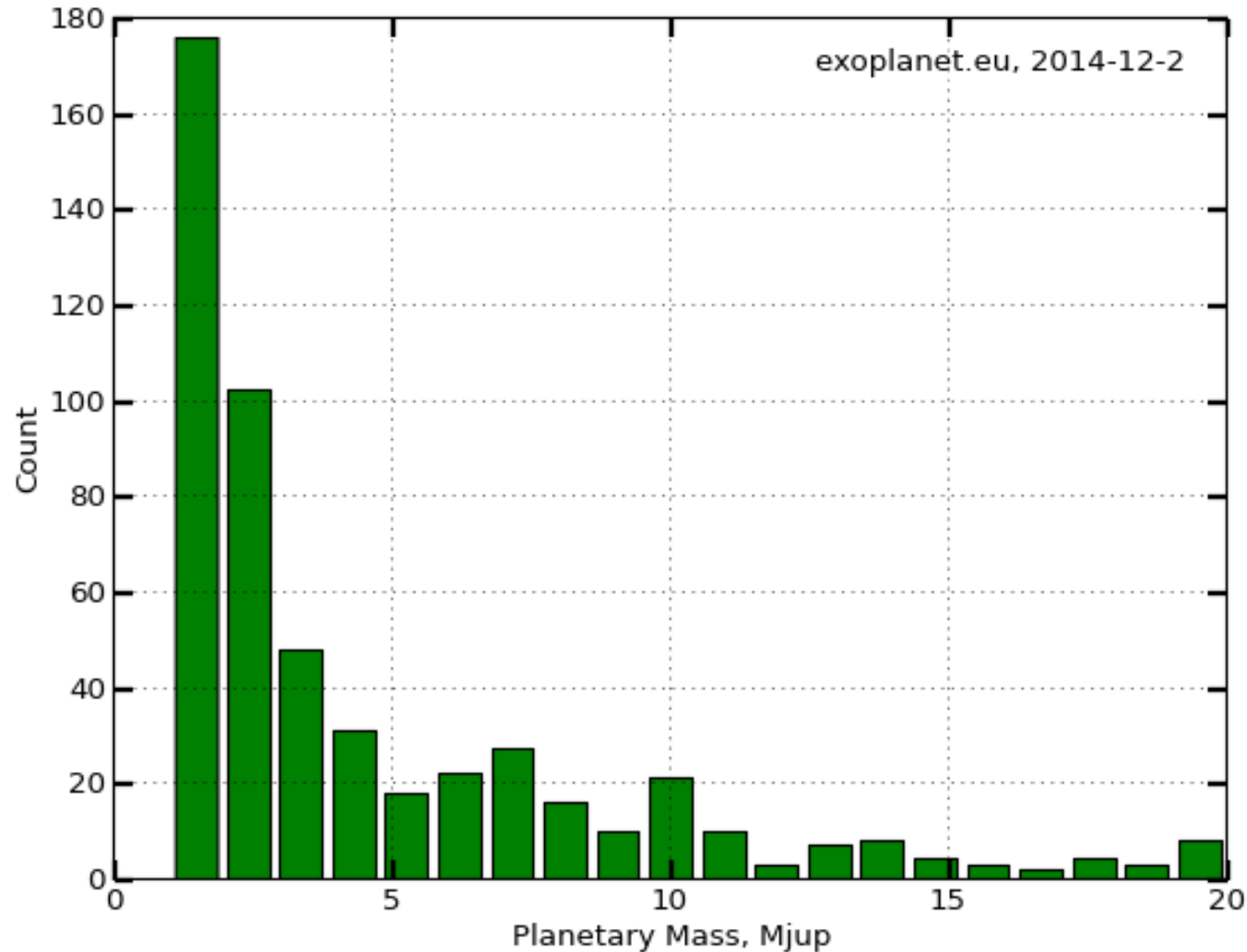


Maybe 1000s of bright ($V < 14$ mag) ACTUAL F-G-K members



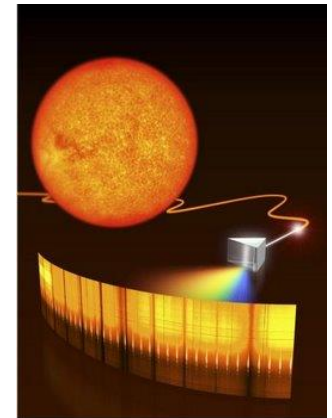
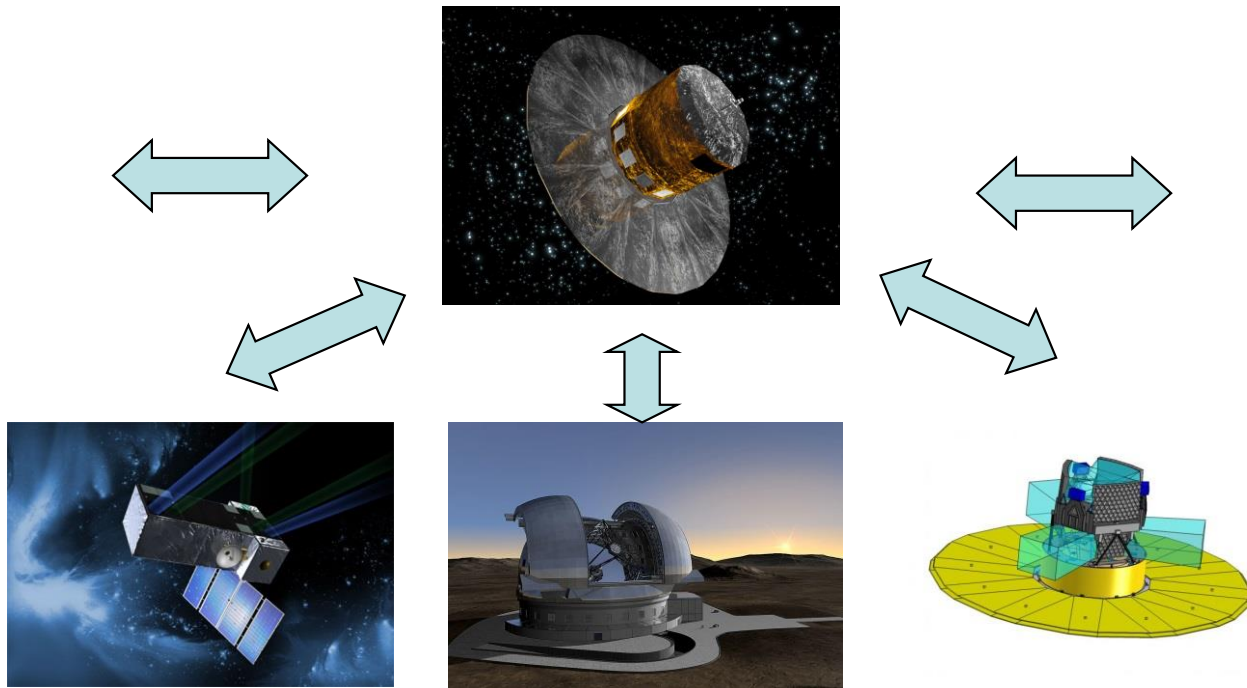
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Gaia and Young Stars



Unique exploration of the GP/BD transition region of companions to 1000s young stars in a regime of separations mostly inaccessible to DI

Gaia - Synergies



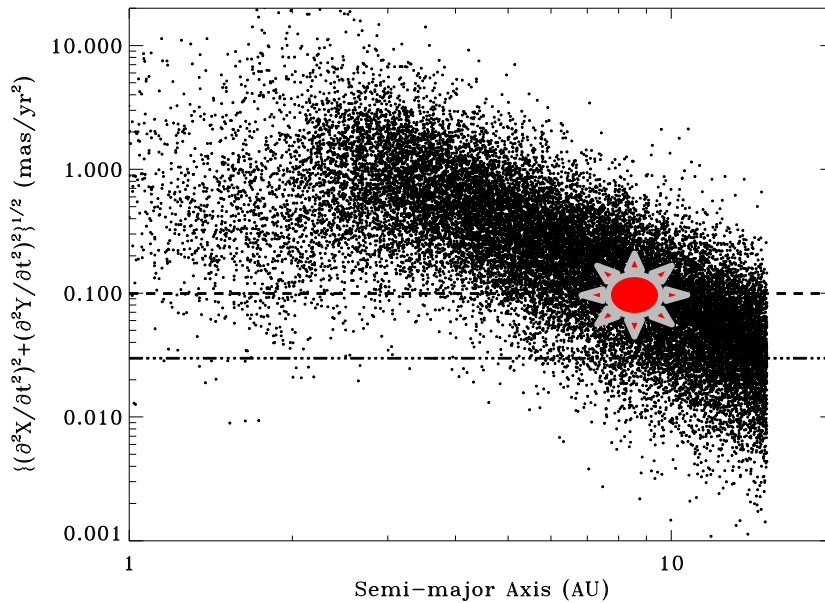
A Laser Comb for Astronomy
(Artist's Impression)
ESO Press Photo 28a/08 (4 September 2008)

- **Gaia & spectroscopic characterization observatories (e.g., JWST, E-ELT)**
- **Gaia & transit surveys from the ground (e.g., WASP, HAT, APACHE, NGTS) and in space (CoRoT, Kepler, K2, TESS, PLATO)**
- **Gaia & direct imaging observatories (e.g., SPHERE/VLT, PCS/E-ELT)**
- **Gaia & RV programs (e.g., HARPS(-N), ESPRESSO, CARMENES, and the likes)**
- **Gaia & ground-based and space-borne astrometry**

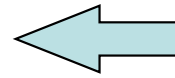


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Gaia + DI/HCI: Example



Accelerations in Gaia astrometry from companions orbiting the SPHERE GTO target sample with $V < 12$, $d < 50$ pc

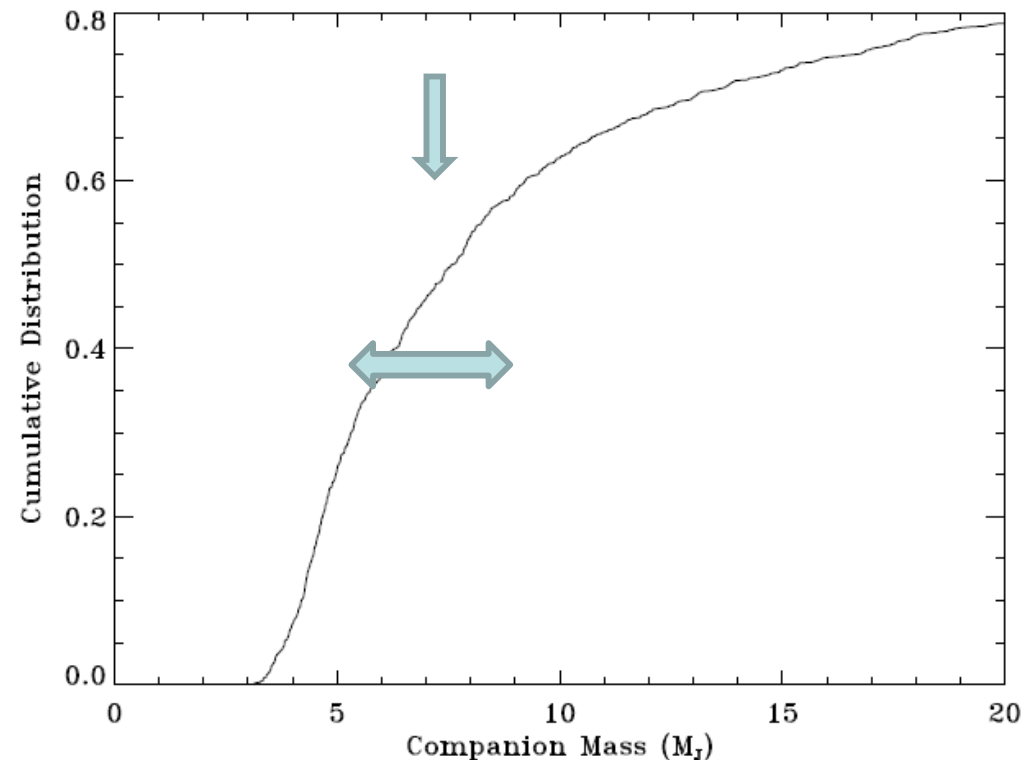


Bonavita, Sozzetti et al. in prep.

For β Pictoris:

$$a_x = 110 \mu\text{as/yr}^2 - a_y = 30 \mu\text{as/yr}^2$$

Mass CDF from Gaia measurements of the companion to β Pictoris





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Finding Nearby Transiting Intermediate-Separation GPs

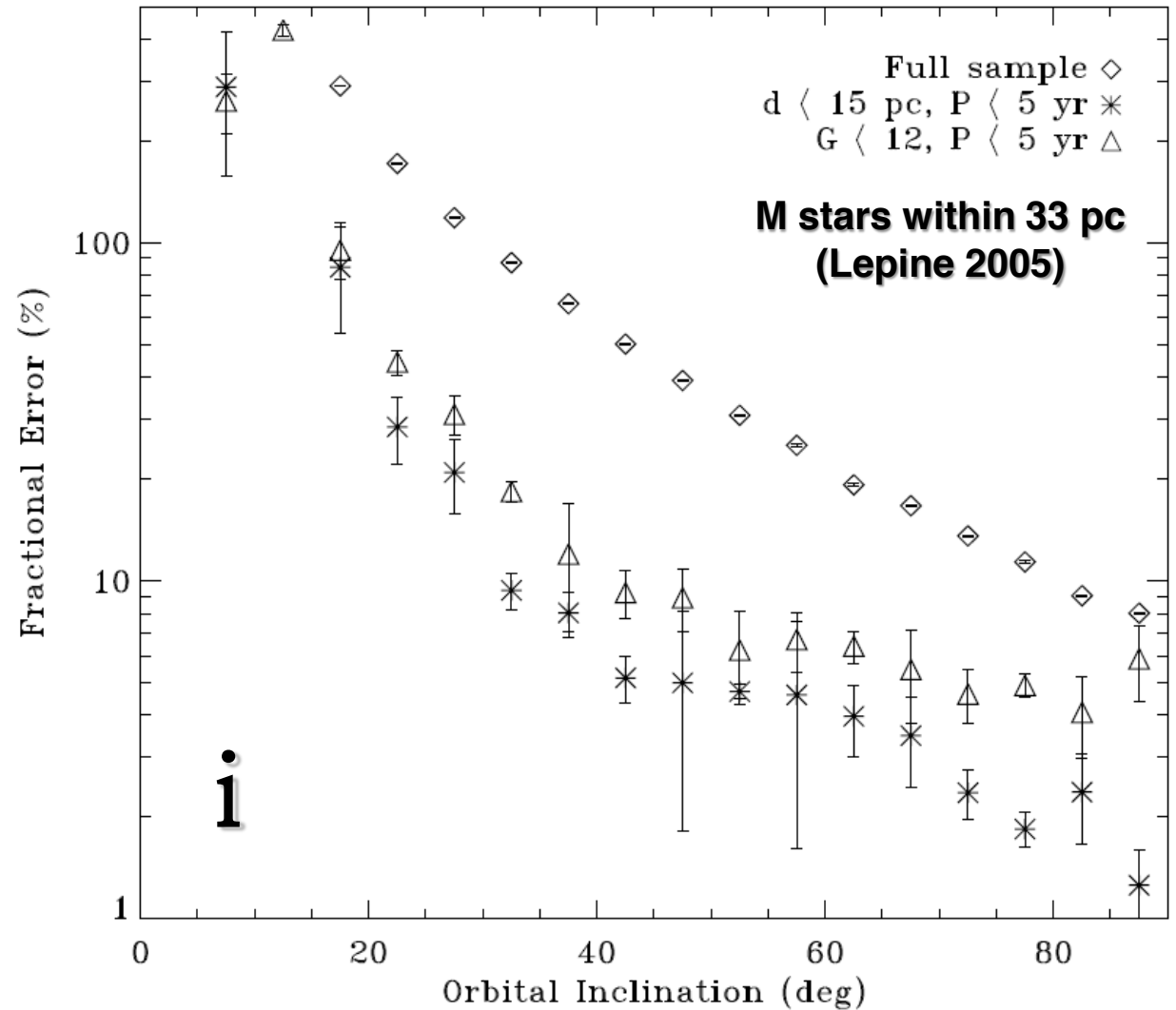


Sozzetti et al. 2014

For well-measured,
quasi-edge-on orbits,
 i is measured to 2-3%

Gaia may find hundreds
of candidate transiting
giant planets
around F-G-K-M dwarfs
of all ages and $[\text{Fe}/\text{H}]$.

Some may be
really transiting!



Follow-up efforts, possible targets for JWST

Synergy with RVs

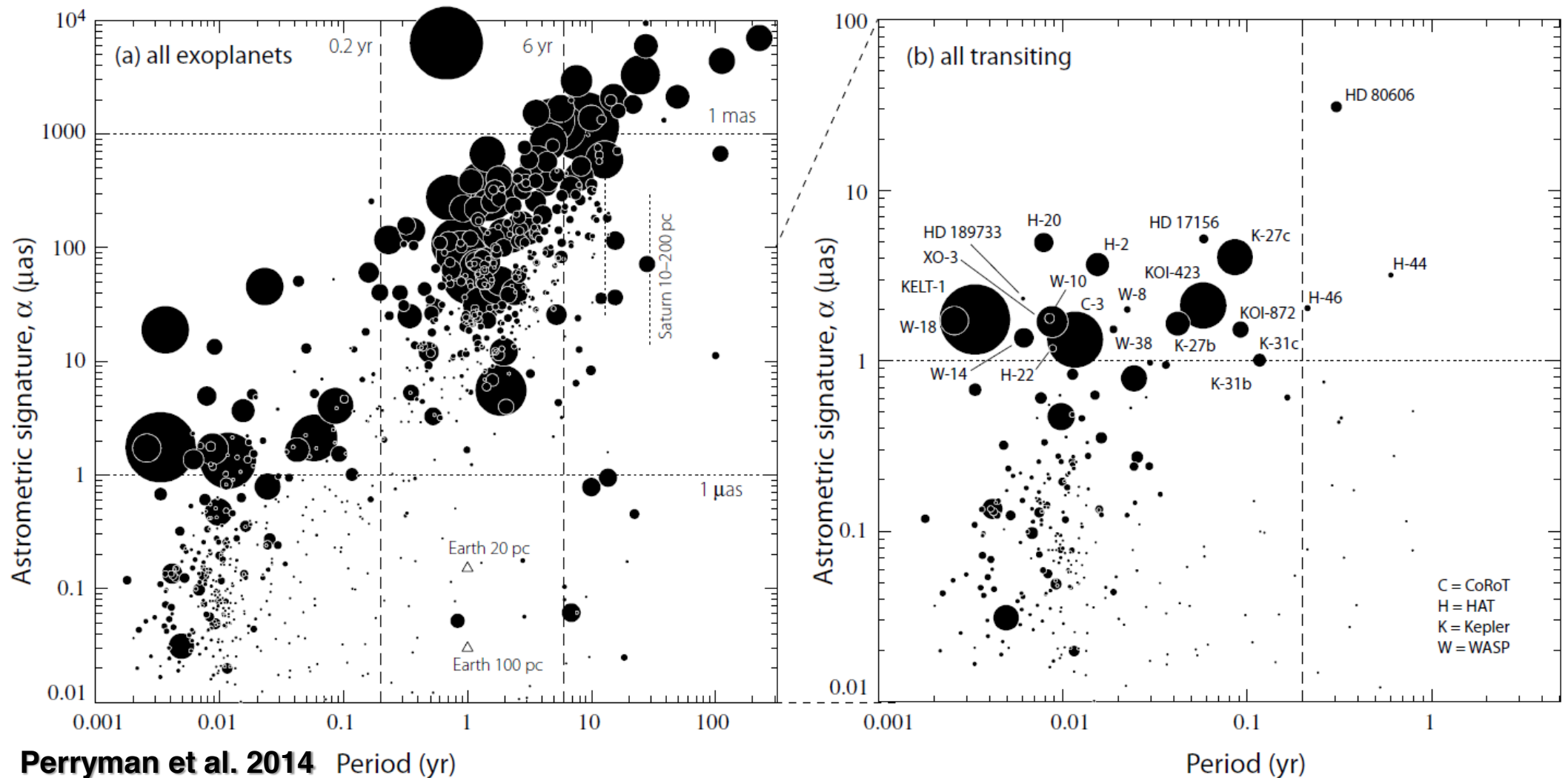
- Complete characterization of systems architectures across orders of magnitude in mass and orbital separation
- Refinement of known orbits (both ways)
- Complete dynamical stability studies in multiple systems (coplanarity!)
- Very important synergy with historical (e.g., HARPS), new-ish (e.g., HARPS-N), and upcoming (ESPRESSO, IR instruments) RV surveys



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Gaia & Known Planets



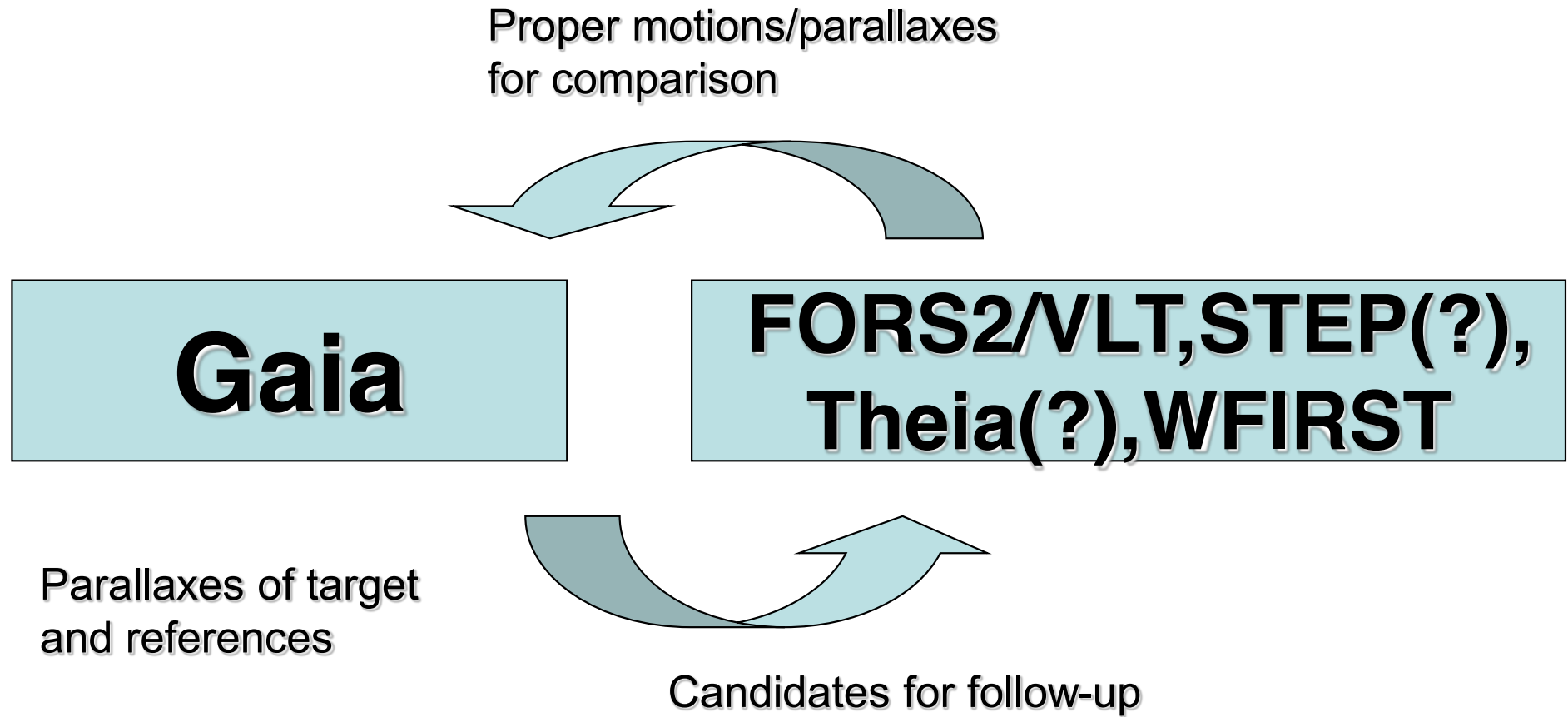
Target Selection

- In early 2017, >90% of parallaxes for (well behaved?) stars observed by Gaia are delivered...
- Elected primary source of the TESS/PLATO input catalogs of $>2 \times 10^6$ bright dwarf stars (with negligible giant star contaminants)
- Significant reduction in astrophysical false positives (know what's in the pixel!)



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Gaia & Ground-Space Astrometry



Combined analyses can profit from large time baseline, particularly when Gaia intermediate astrometry data will become available