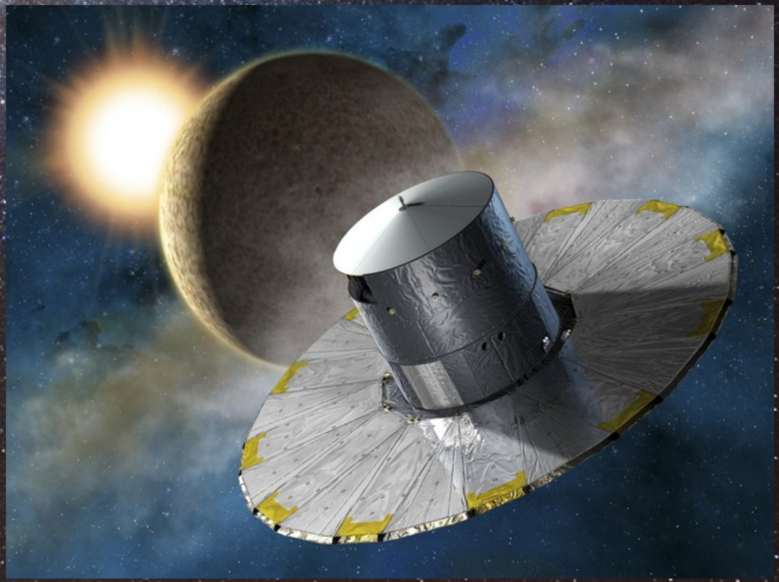
The Impact of Gaia on Our Knowledge of Stars and Their Planets



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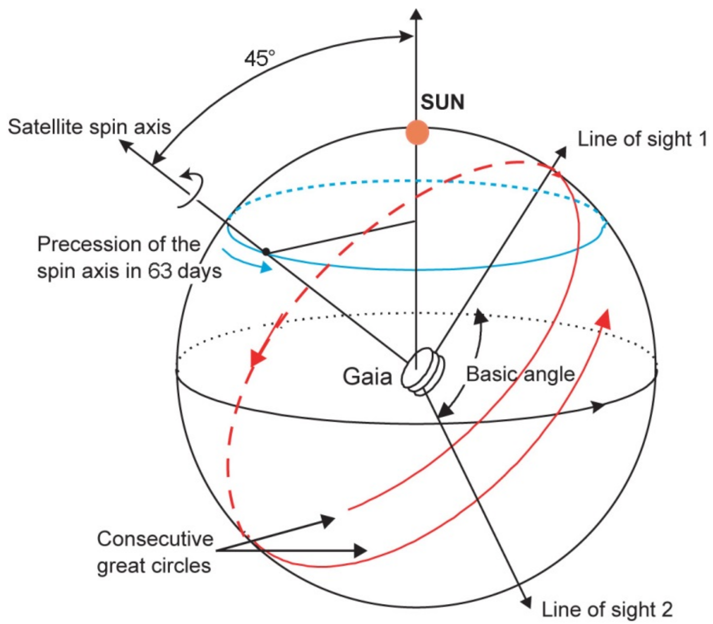
The impact of Gaia on our knowledge of stars and their planets has been inexistent.

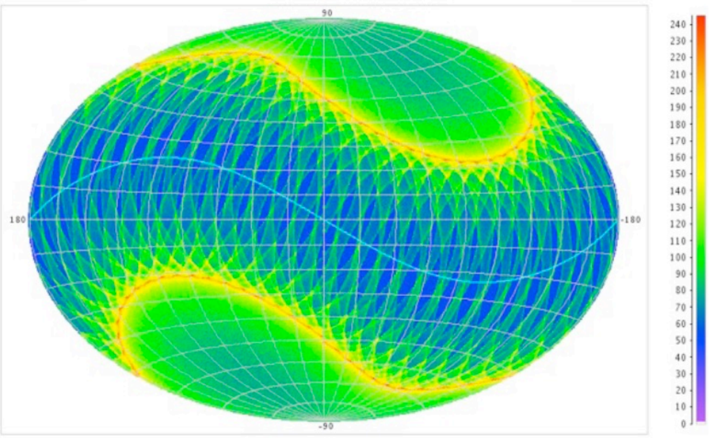
So far.

This is bound to change very soon.

A Space Astrometry Revolution!

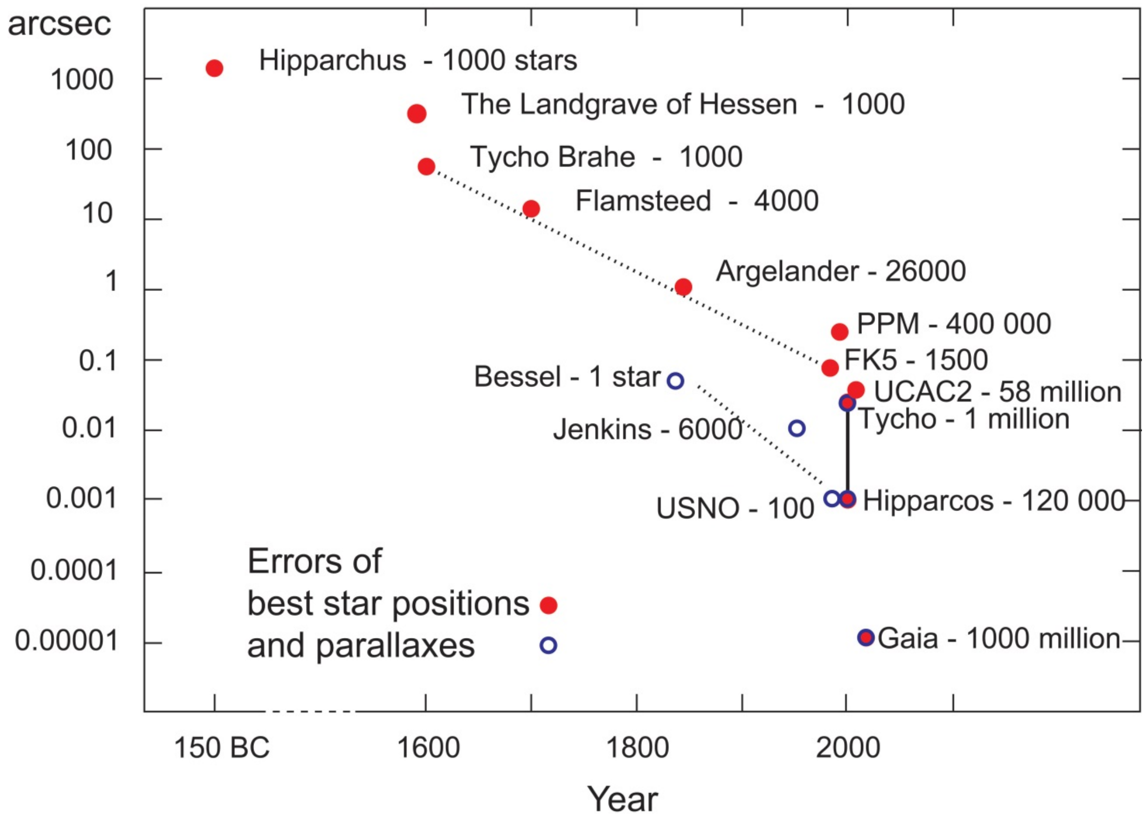


Number of FoV crossings per star (5 yr)



Equatorial projection

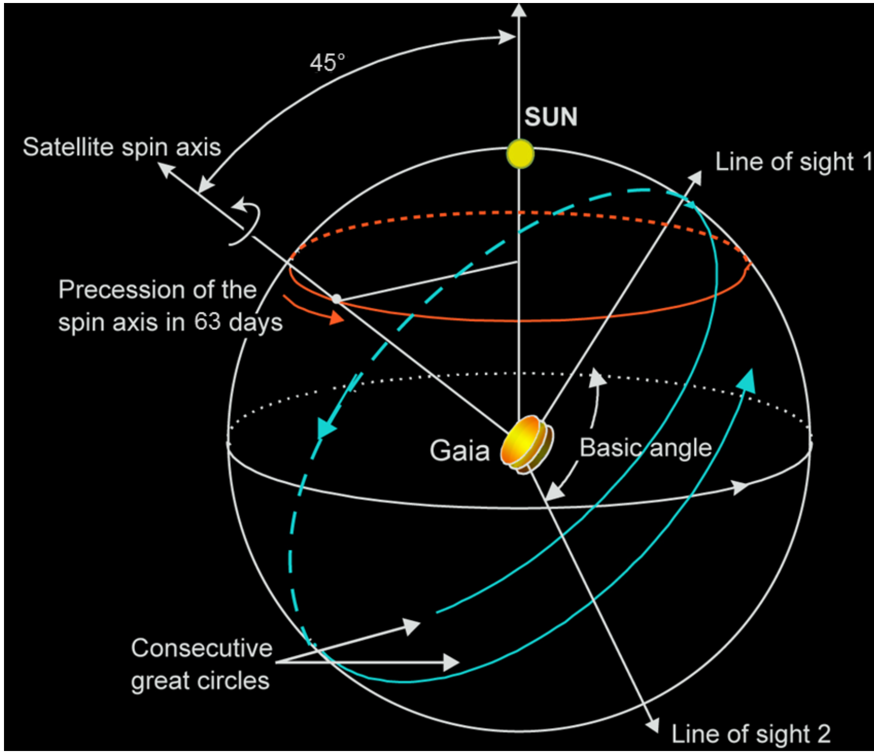
At Gaia's G=20.7 survey limit: >1x10^9 stars



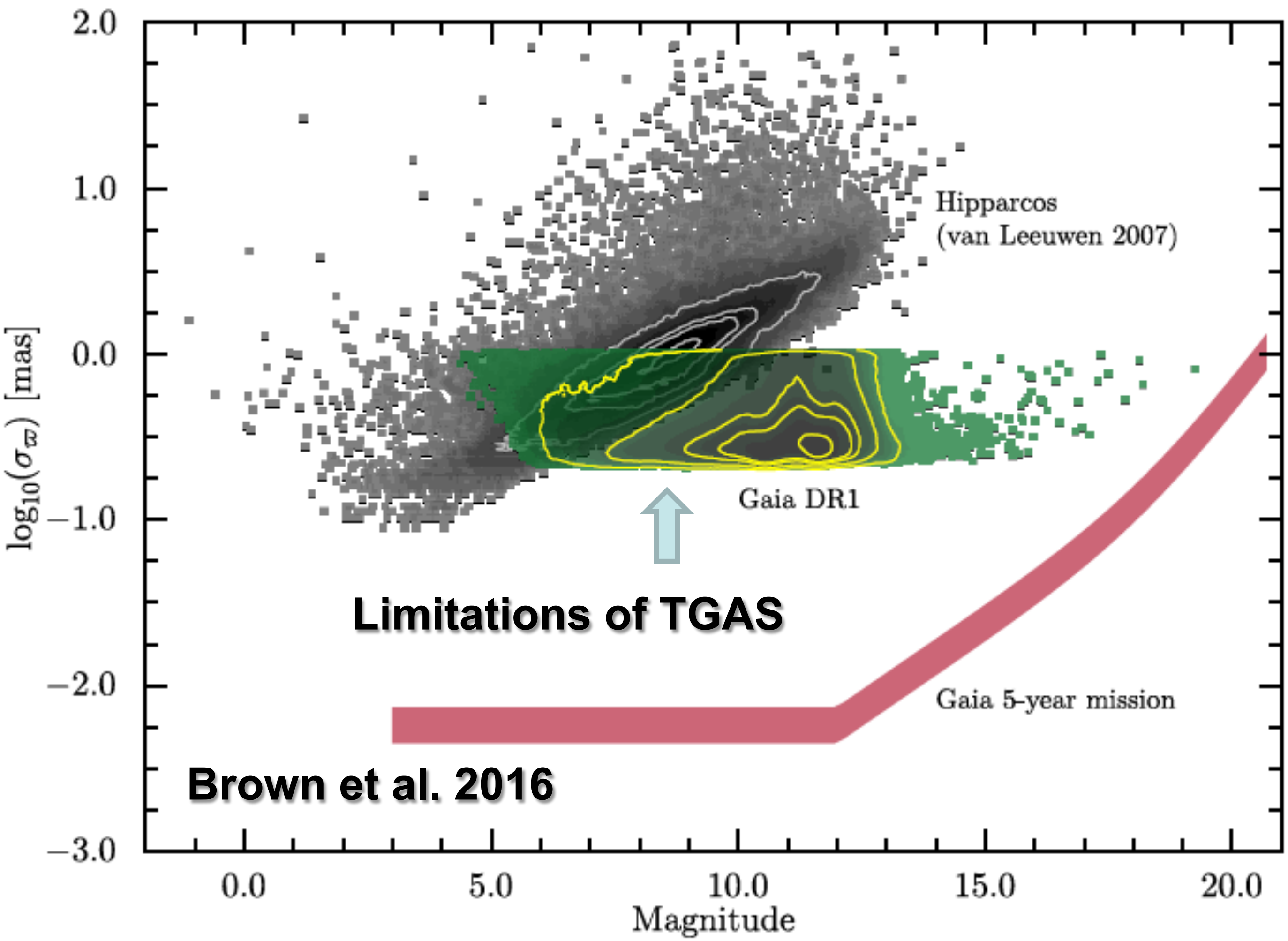
µas astrometry comes of age...

How is Gaia doing?

- Launch 19 December 2013 with Soyuz from Kourou (French Guyana)
- Gaia in routine operations at L2 since July 2014
- 1,000 days routine phase reached 20 April 2017
- Operations: nominal
- some 87 billion transits observed
- Bright limit around G=3 mag
- Very bright stars treated separately
- Nominal 5-year mission ends mid-2019



Gaia DR1



>200 papers based on Gaia DR1 since 2016-09-14

Handling 'Issues'

- **Contamination**
  - Last decontamination in August 2016; no sign of transmission loss yet
- **Micro-clanks and micrometeoroids**
  - Taken into account in data processing for Gaia DR2
- **Basic Angle Variation**
  - Corrected with Basic Angle Monitor data for Gaia DR1 and DR2; more sophisticated analysis planned for the future
- **Stray light**
  - Impact on faint sources; on-board software modified from read-out dominated to background dominated case for faint objects
- **Radiation damage**
  - First signs visible, but less than anticipated before launch; pre-launch calibration work will become relevant in the future

Gaia DR2: 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 (ALL Gaia-only)

* G and integrated G_{BP} and G_{RP} photometric fluxes and magnitudes for all sources

* Median radial velocities for sources brighter than $G_{RVS} = 12$

* For stars with G < 17, estimates of T_{eff} and when possible (π>0!) A_G & E[BP-RP] based on integrated photometry, M_{bol} and R_* when σ(π) < 20%

* Photometric data for a sample of variable stars

* Epoch astrometry for a pre-selected list of > 10 000 asteroids

GDR2: more and better data

- Parallaxes:
  - a factor of several (I hope!) better than DR1

- stellar parameters:
  - T_{eff}: ~320K error
  - A_G: ~0.5mag error
  - E[BP-RP]: ~0.3mag error
  - luminosity: ~11% error
  - radius: 7-13% error

Courtesy C. Bailer-Jones

After Gaia DR2

LESSON LEARNED:

- Complex interfaces between DPAC elements
- Need to produce catalogues providing scientifically significant steps forward
- This hampers the possibility to have DRs on a yearly basis

THEREFORE:

- DR3 scheduled for 2020
- final DR in 2022 (three yrs after end of mission)
- See https://www.cosmos.esa.int/web/gaia/release

Gaia Extension

- Nominal mission end: mid-2019
- Likely end of mission: end-2023 ± 1 year
- GST prepared with the help of many the science case for the ESA advisory bodies
- Science case was prepared for a 5 years extension, but ESA extension cycle is 2+2 years so Gaia is in for the preliminary, scientific, extension approval for mid-2019-20
- End-2018 definitive extension for mid-2019-20 and preliminary scientific extension approval for 2021-22
- The extension decision is expected in Fall 2017

CU4-NSS Timeline

- CU4-NSS handles astrometric, photometric and spectroscpic modeling of non single stars (including exoplanet orbits)

- It requires input of non-well-behaved stellar samples

- CU3 to produce a first set based on the 5-parameters astrometric solution for DR2

- NSS are modeled based on highly calibrated data: not trivial!

- First NSS processing results thus expected for DR3 (2020)

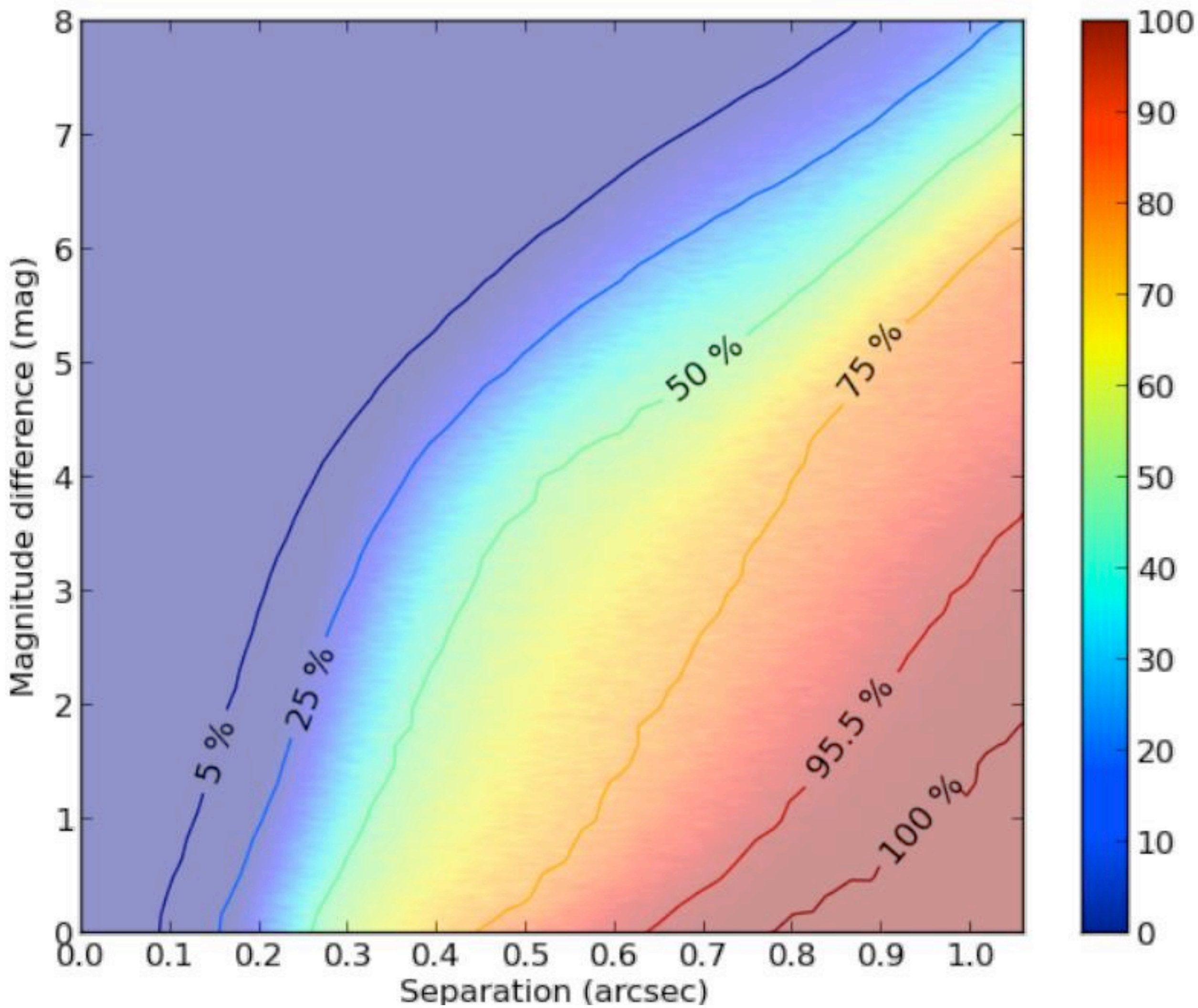
The Impact of Gaia

- Gaia as a target selector
- Gaia as a target characterizer
- Gaia as a planet finder

Populating the TIC/PIC

- Large-scale simulations (all-sky) produced by DPAC's CU2 team (exercise, but you get the feeling)
- Simple cutoffs in G mag and d allow to limit 'contaminants' to within <1% (with ALL later than F5V stars identified)
- Can do even better (<0.1%) using Teff/logg info from onboard spectrophotometry and spectroscopy (logg not coming in DR2)

Know what's in thy pixels

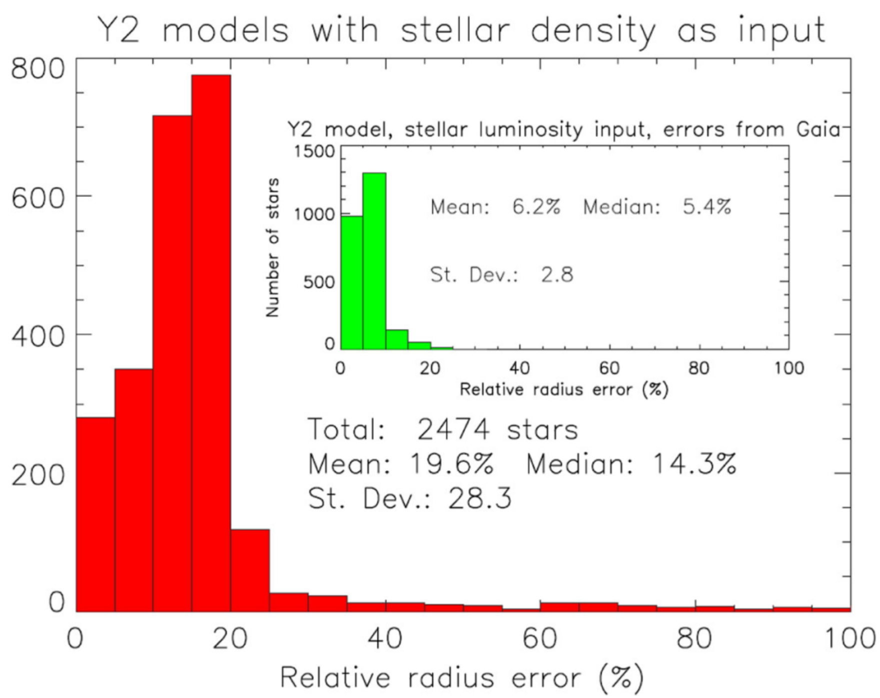


Mind you: Independent of magnitude of the primary

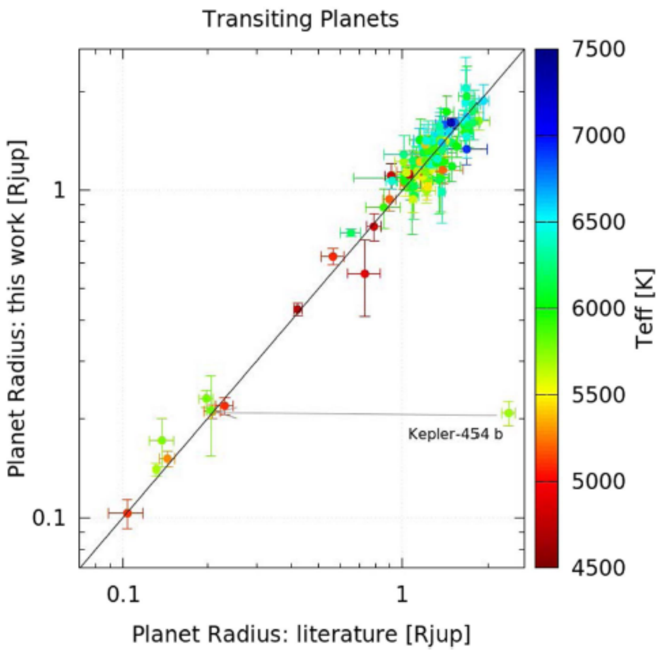
Courtesy Jos de Brujine

Calibration of the Hosts

Take Gaia parallaxes, and then do it your way!



Sozzetti & Damasso 2015

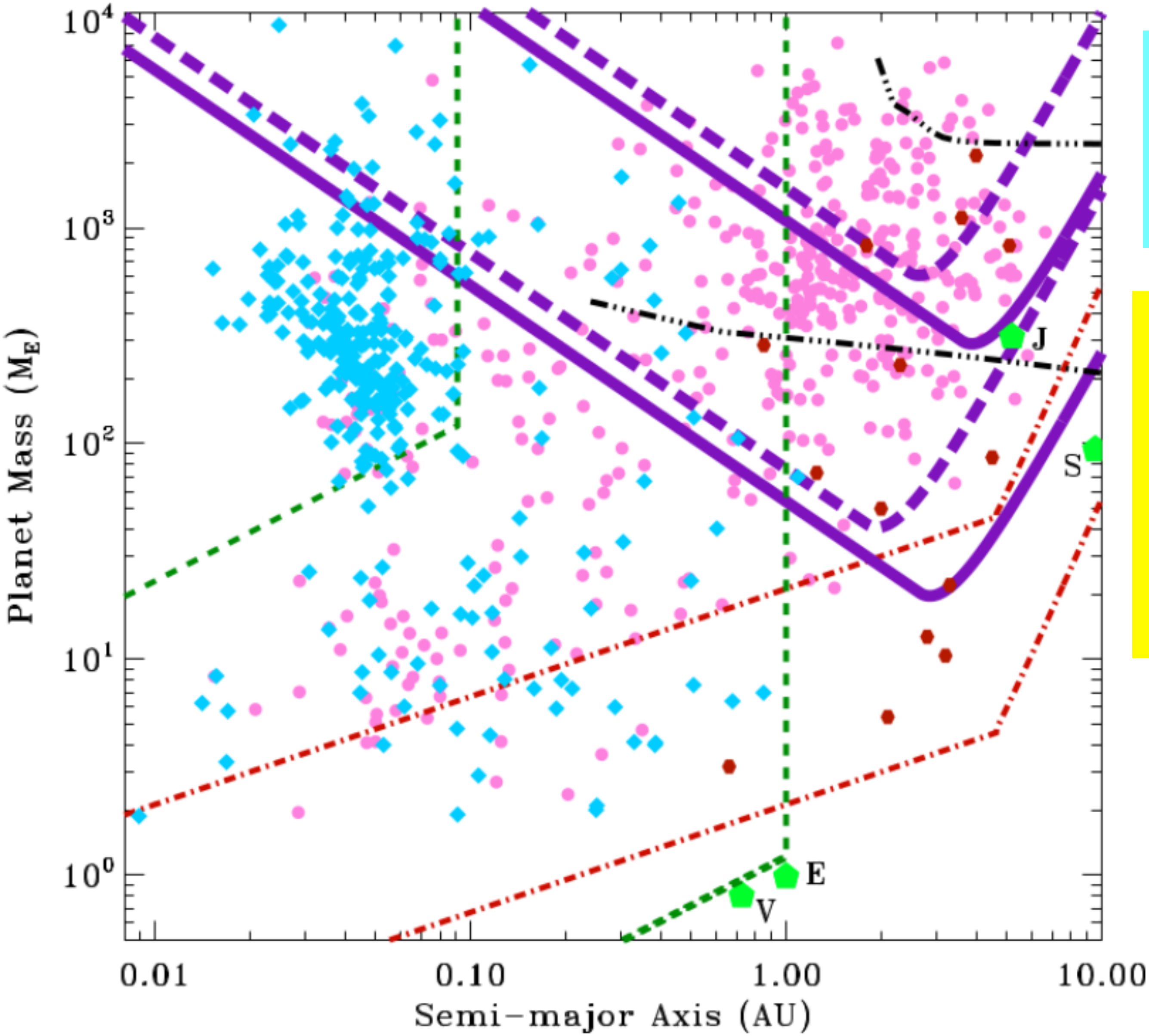


Stassun et al. 2017

DR2:
Bright (V<13) F-G-K stars (D<200-300 pc) and not very faint (V<16) M dwarfs (D<50-60 pc) *might* have distances determined to a few %

→ **Derive 'accurate' stellar radii to within 5% or so**

Gaia Discovery Space

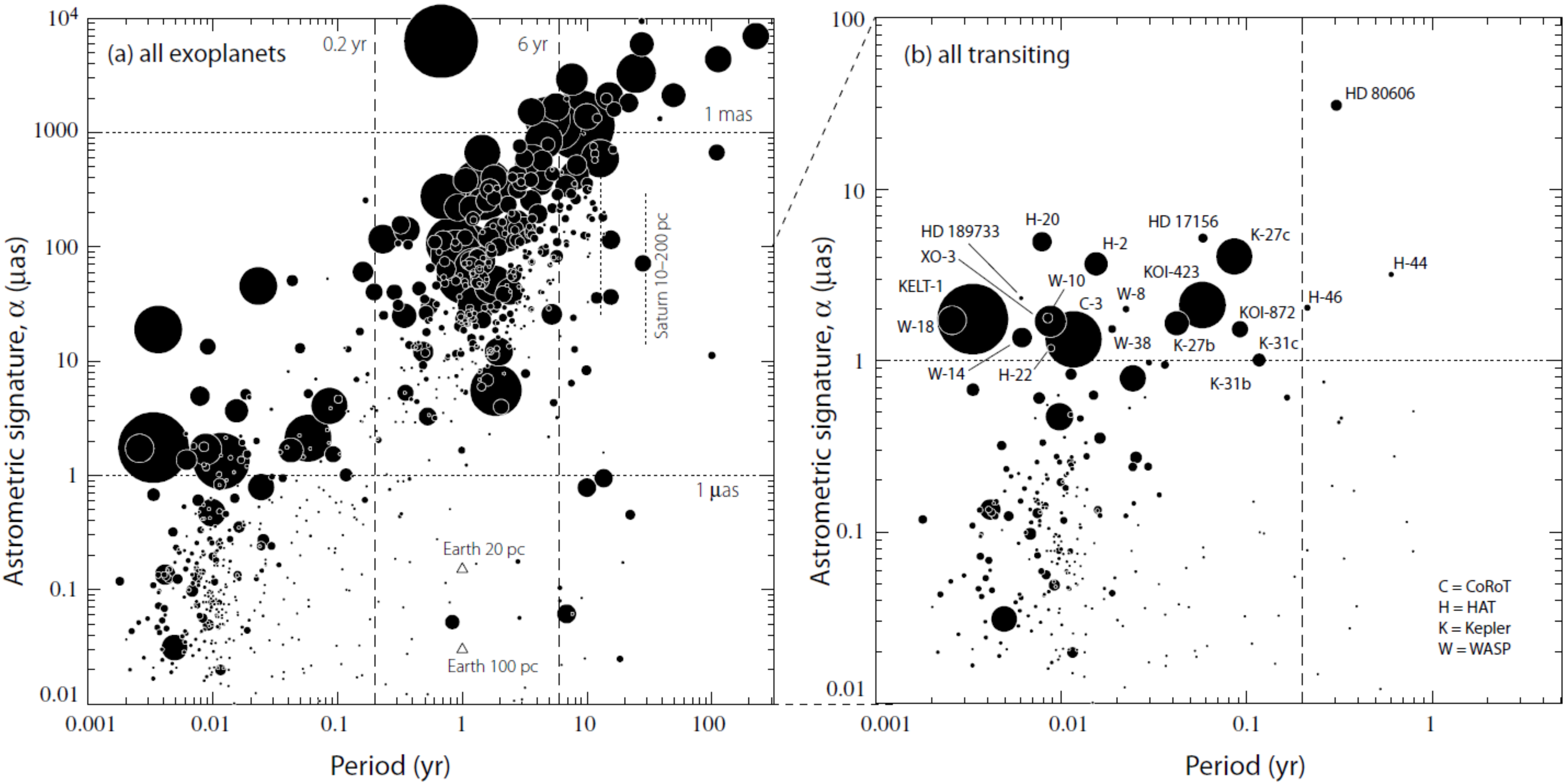


Unbiased, magnitude-limited planet census of maybe 10^6-10^7 stars

On the order of >10^4 NEW gas giants (< 15 M_{JUP}) around A through M dwarfs Numbers might as much as triple for a 10-yr mission

Lattanzi et al. 2000,
Sozzetti et al.2001
Casertano et al. 2008
Perryman et al. 2014
Sozzetti et al. 2014
Sahlmann et al. 2014

The Gaia Legacy

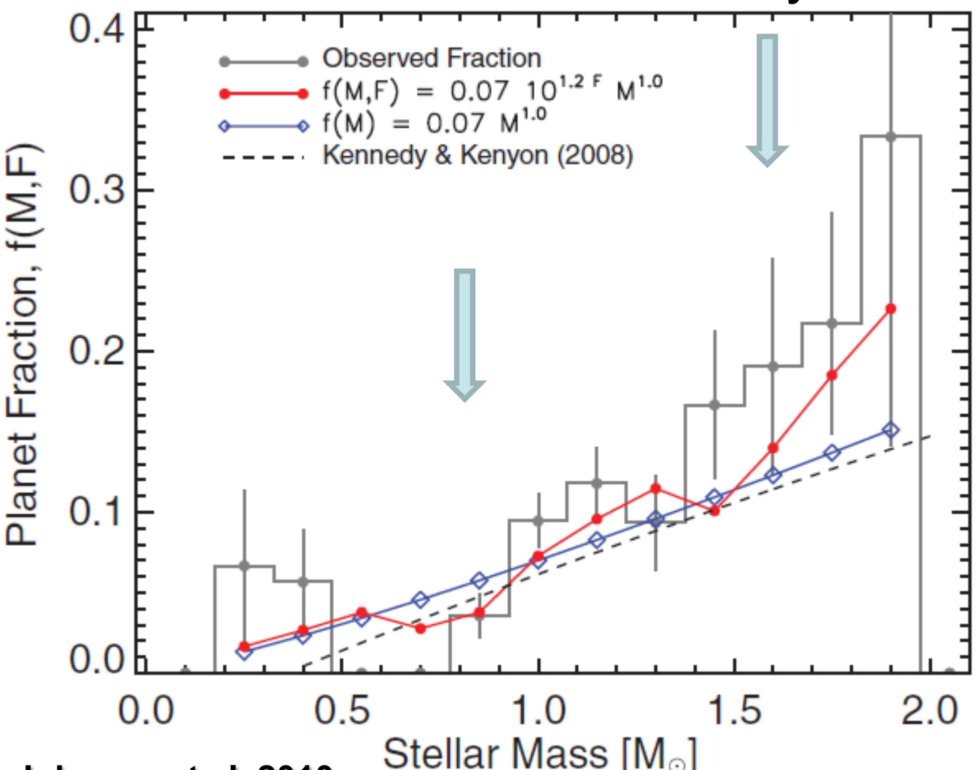


Gaia will test the fine structure of GP parameters distributions and frequencies (including the GP/BD transition), and investigate their changes as a function of stellar mass, metallicity, age, and multiplicity with unprecedented resolution

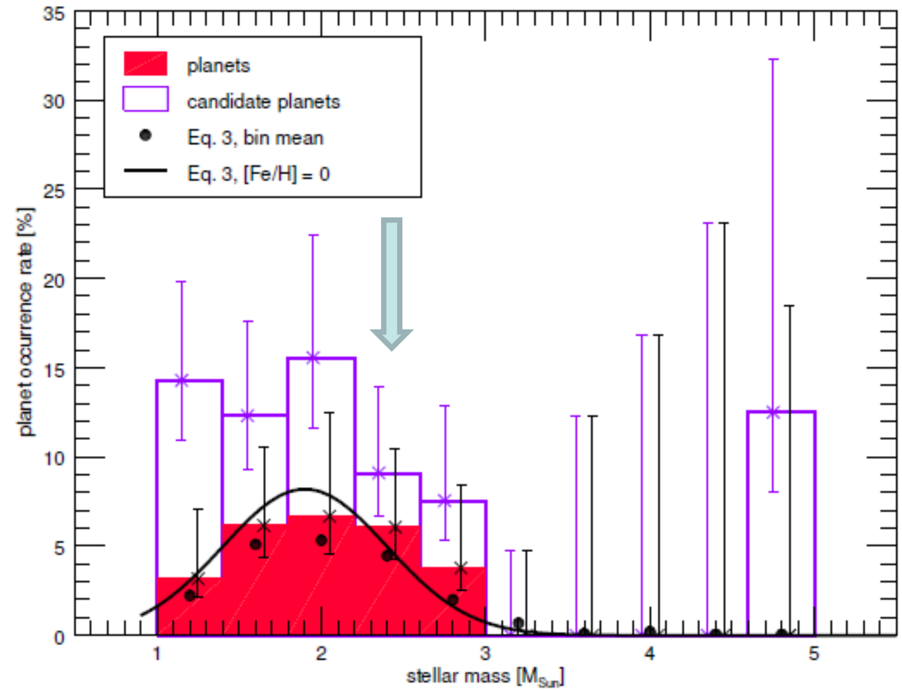
M_*: Frequencies

Gaia: 10^4 stars in a bin!

Today: 10^2 stars in a bin!

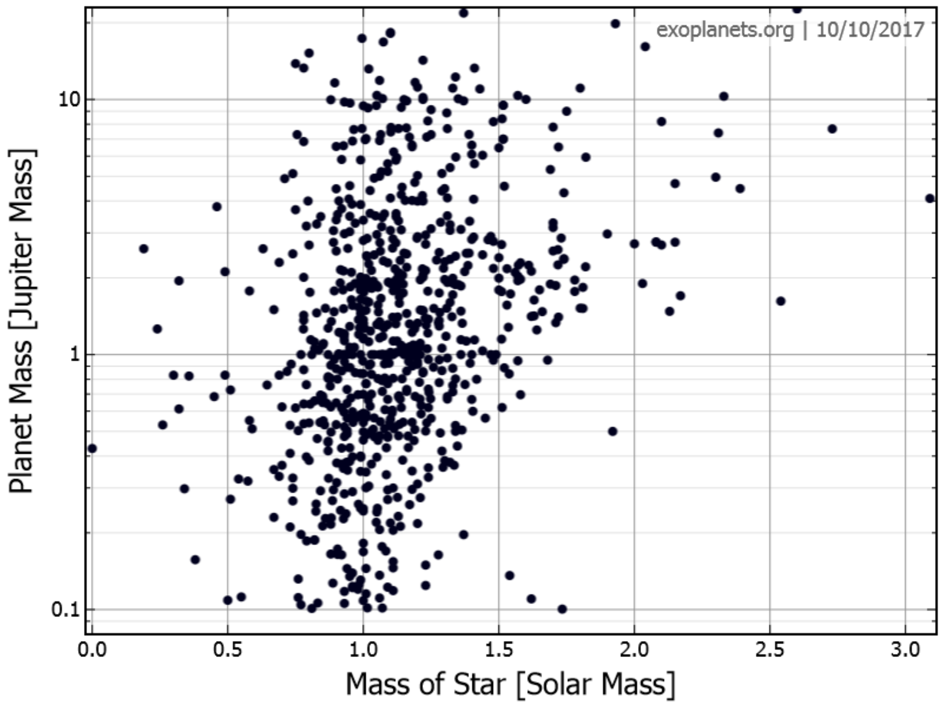


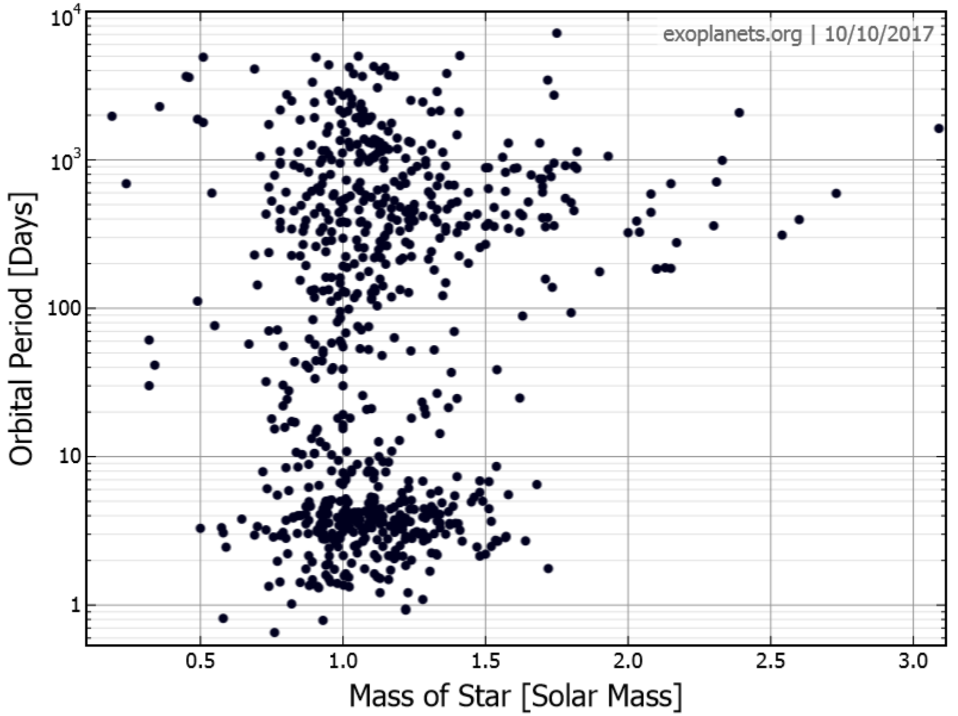
Johnson et al. 2010



Reffert et al. 2015

M*: Correlations





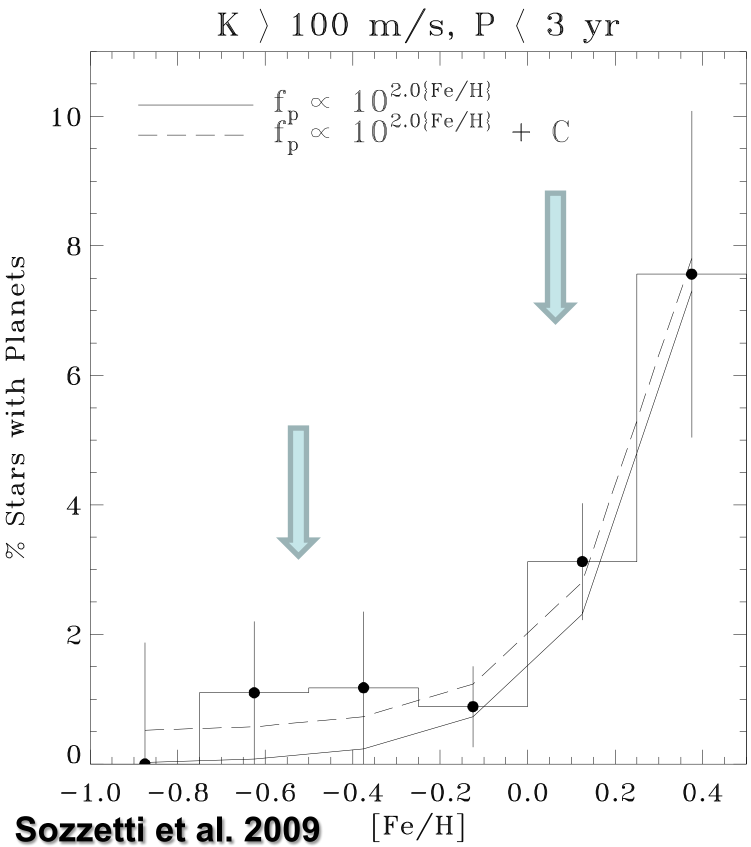
- Are more massive planets preferentially found around more massive primaries?
- Do lower- and higher-mass star only host longer-period companions?

Gaia will allow you to answer with 10x more planets!

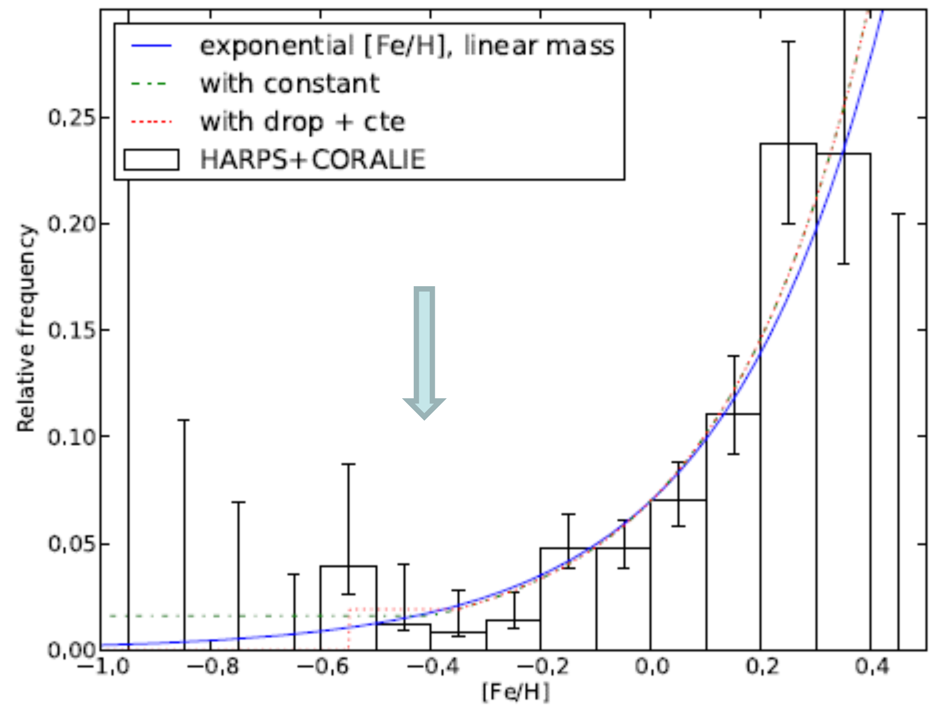
[Fe/H]: Frequencies

Gaia: 10^4 stars in a bin!

Today: 10^2 stars in a bin!

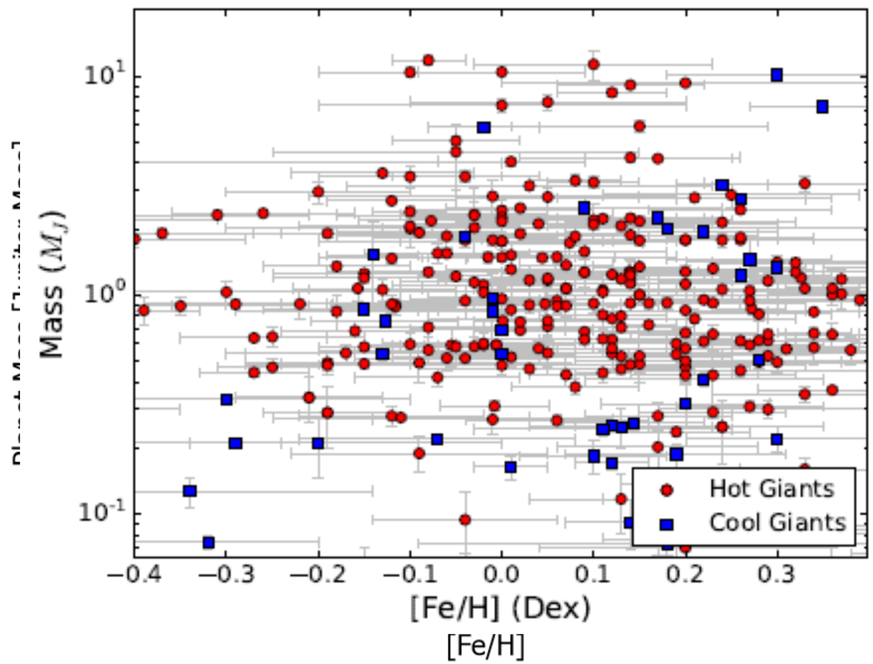


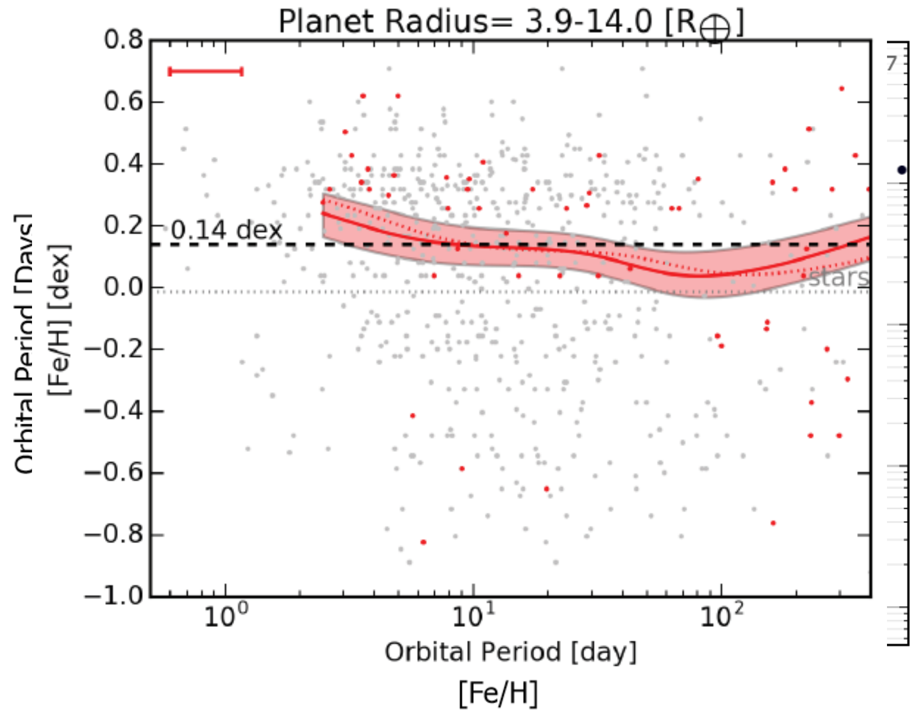
Sozzetti et al. 2009



Mortier, Santos, Sozzetti et al. 2012, Mortier et al. 2012

[Fe/H]: Correlations





Santos et al. 2017 **Thorngren et al. 2016** **Sozzetti 2004** **Mulders et al. 2016**

- Are more massive planets preferentially found around low-[Fe/H] primaries?
- Do low-[Fe/H] stars host longer-period companions?
- What is the actual [Fe/H] limit for giant planet formation?

Gaia will allow you to answer with 10x more planets!

η_E and Solar System analogs

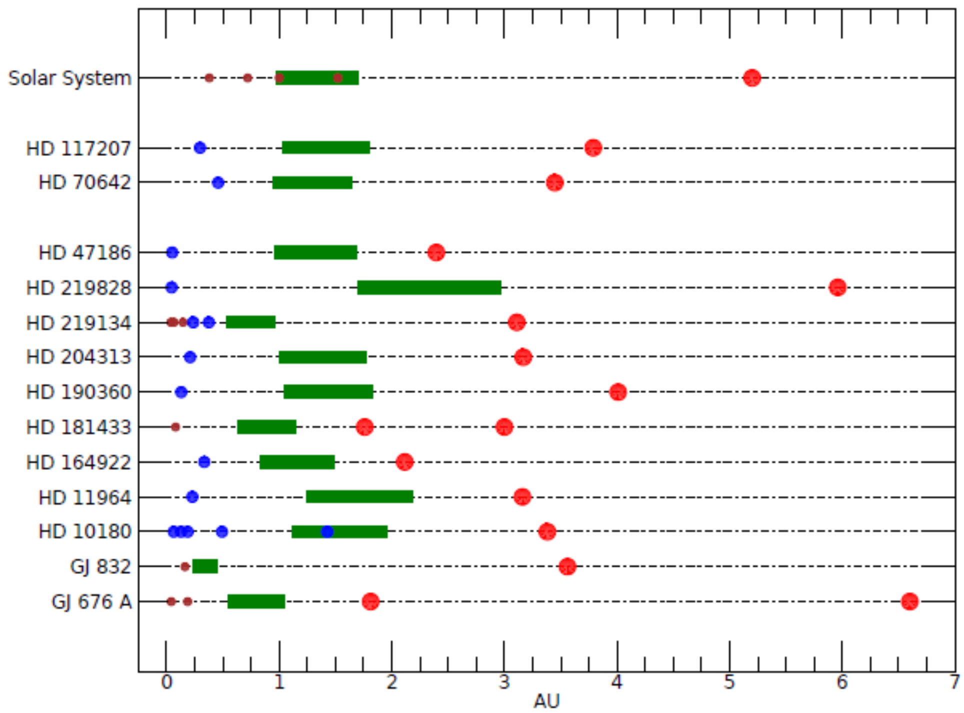
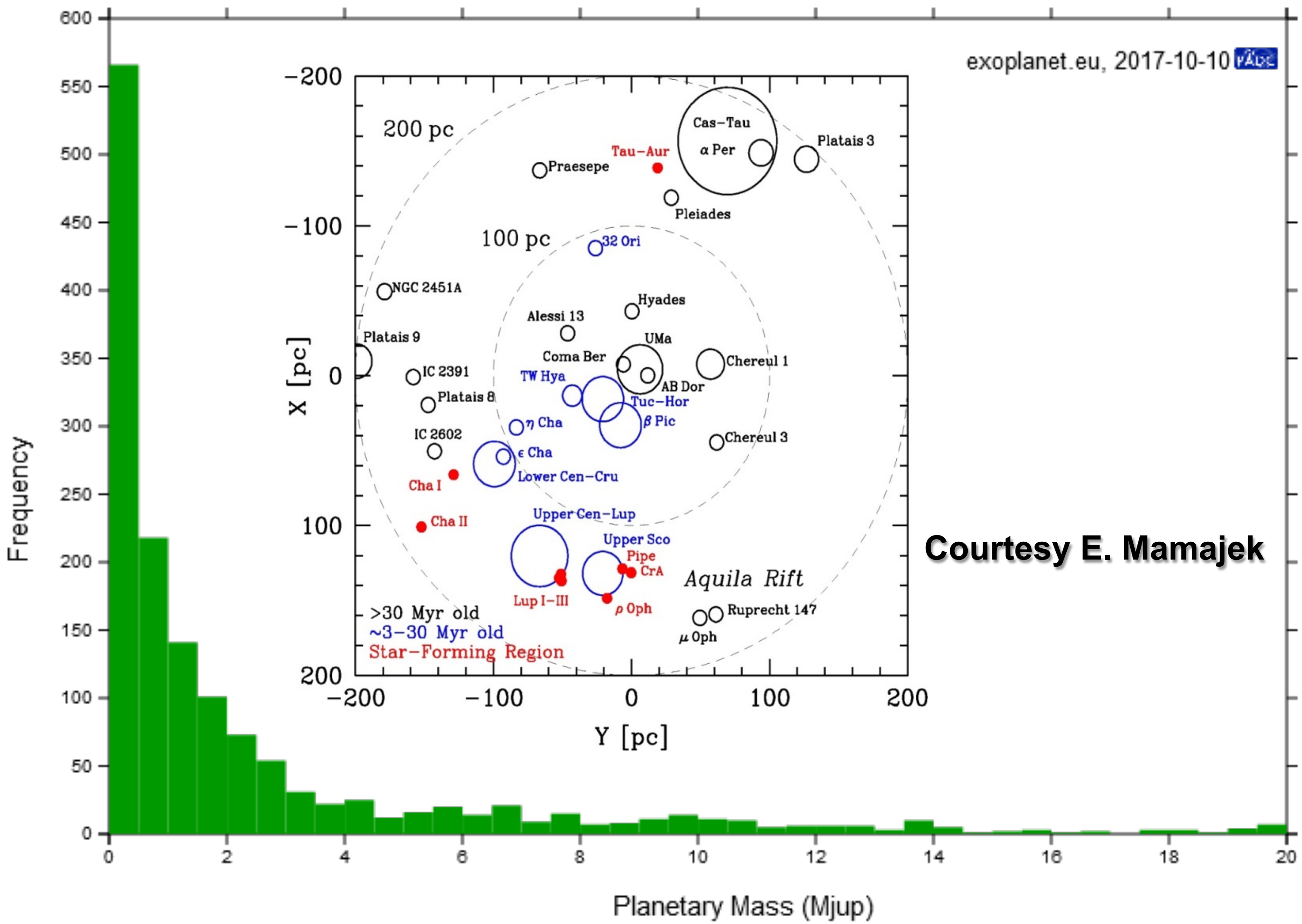


Table 2. Occurrence rates of "Earth-like planets"

Type of star	Type of planet	Approx. HZ boundaries* $[S/S_\oplus]$	Occurrence rate [%]	Reference
M	1-10 $M_\oplus$	0.75-2.0	41^{+54}_{-13}	1
FGK	0.8-2.0 $R_\oplus$	0.3-1.8	$2.8^{+1.9}_{-0.9}$	2
FGK	0.5-2.0 $R_\oplus$	0.8-1.8	34 ± 14	3
M	0.5-1.4 $R_\oplus$	0.46-1.0	15^{+13}_{-6}	4
M	0.5-1.4 $R_\oplus$	0.22-0.80	48^{+12}_{-24}	5
GK	1-2 $R_\oplus$	0.25-4	22 ± 4	6
FGK	1-2 $R_\oplus$	~0.9-2.2[†]	~0.01[†]	7
FGK	1-4 $R_\oplus$	0.35-1.0	$6.4^{+3.4}_{-1.1}$	8
G	0.6-1.7 $R_\oplus$	0.51–1.95	$1.7^{+1.8}_{-0.9}$	9

A 10-yr Gaia mission could provide a census of > 1 M_{Jup} analogs around most of TESS and PLATO targets (planet hosts and not)

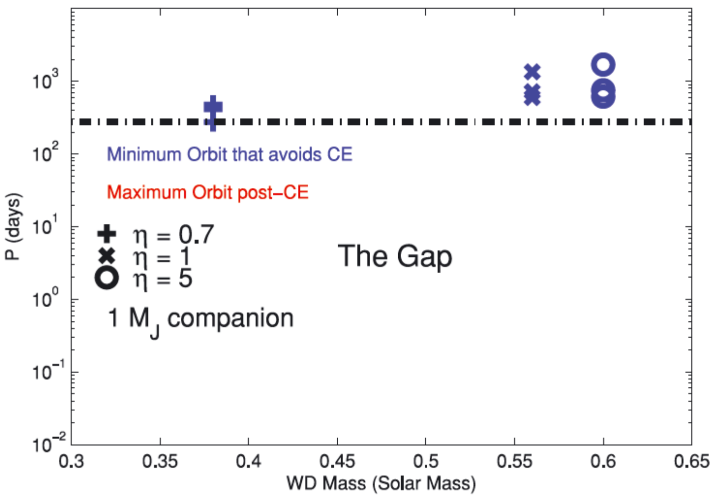
Gaia and Young Stars

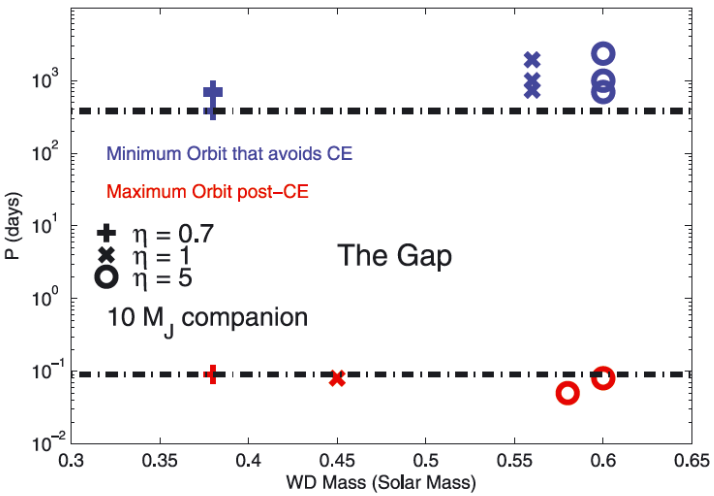


Courtesy E. Mamajek

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

Gaia & Post-MS Stars





White dwarfs in the solar neighborhood

Good to within a factor 2…

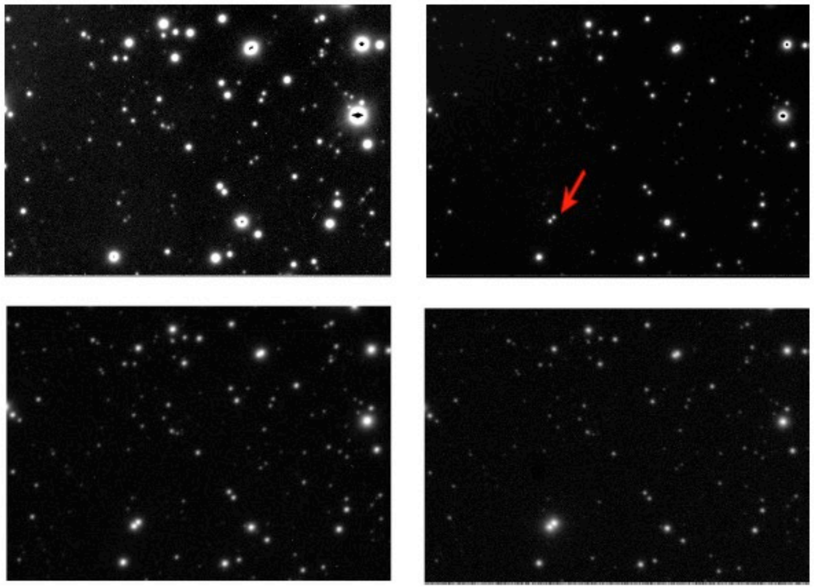
	D<100 pc	D<200 pc
R<13	50	400
R<14	200	1600
R<15	800	6400

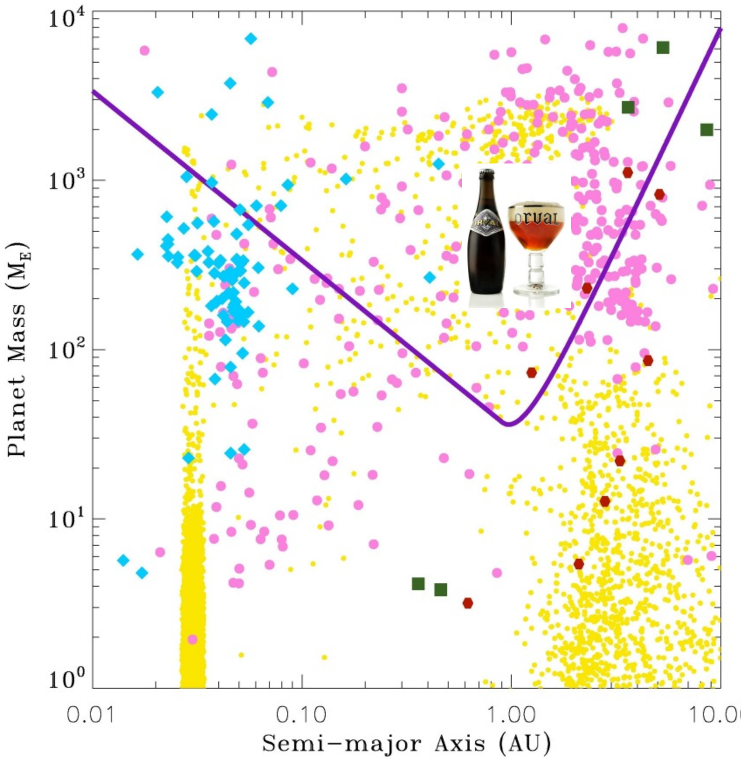
Silvotti, Sozzetti, & Lattanzi, 2015

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

Gaia & UCD Planets

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



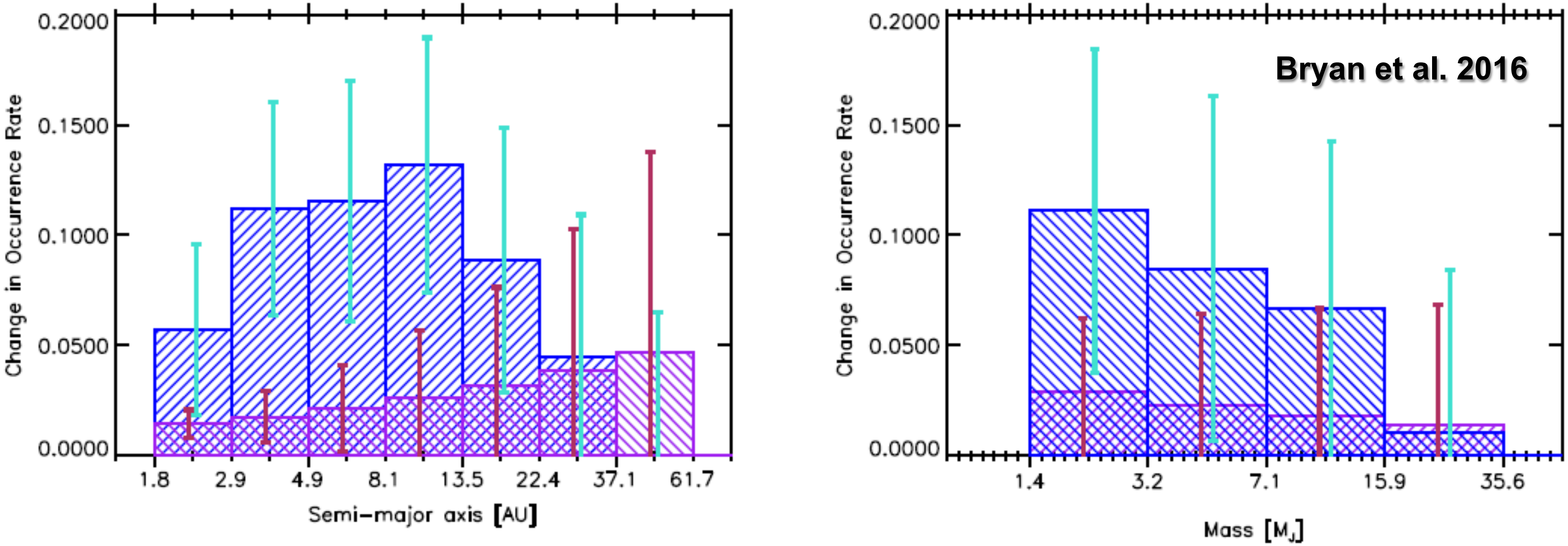


- Found so far only in microlensing events
- Gaia will see ~1000 UCDs of all ages, with sufficient astrometric sensitivity to giant planets within 2-3 AU
- A fundamental test of planet formation!

Sozzetti (arXiv:1406.1388)

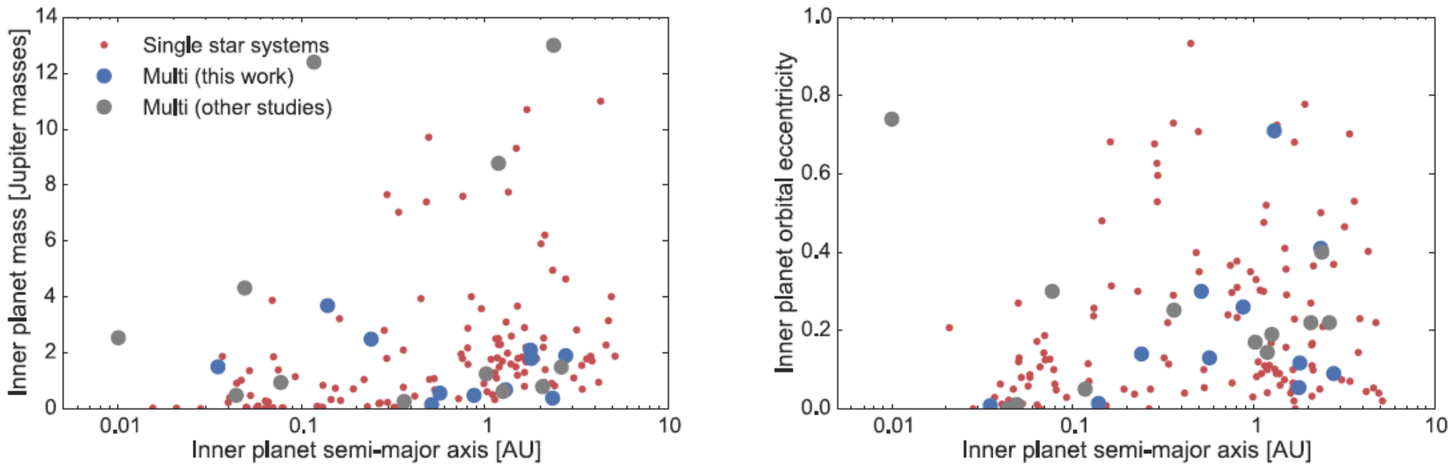
Gaia & Multiple Systems

>50% of 1-GP systems has additional massive companions



- Combine Perryman et al. (2014) and Casertano et al. (2008) results:
- $T_{mission}$= 5 yr:
  >2500 two-planet systems with σ(M)<15%-20%, some 250 I_{rel} measurements
- $T_{mission}$= 10 yr:
  >6000 two-planet systems with σ(M)<15%-20%, some 600 I_{rel} measurements

Gaia and Planets in Binaries



Ngo et al. 2017, but see Moutou et al. 2017

- Are orbital elements distribution of planets in binaries and around single stars the same?
- Are the orbital architectures of giant planet systems in binaries the same as those of planets around single stars?
- How do frequencies depend on binary separation?
- What about all these questions in the circumbinary case?

Gaia is sensitive to giant planets around >10^6 stars: > 50% will be binaries!

gaia

Gaia, Stars, and Exoplanets

SEVENTH FRAMEWORK PROGRAMME

The impact of Gaia on our knowledge of stars and the planets they host:

- Critical for clean target sample selection

- Crucial for accurate determination of stellar properties

- Diversified across orders of magnitude in mass and separation of companions, encompassing all ranges of stellar mass, chemical composition, age, multiplicity

Multi-faceted and far-reaching, i.e. revolutionary!

Gaia to start delivering in the field in April 2018. Stay tuned!