Extra−solar Planets with GAIA: Why & How

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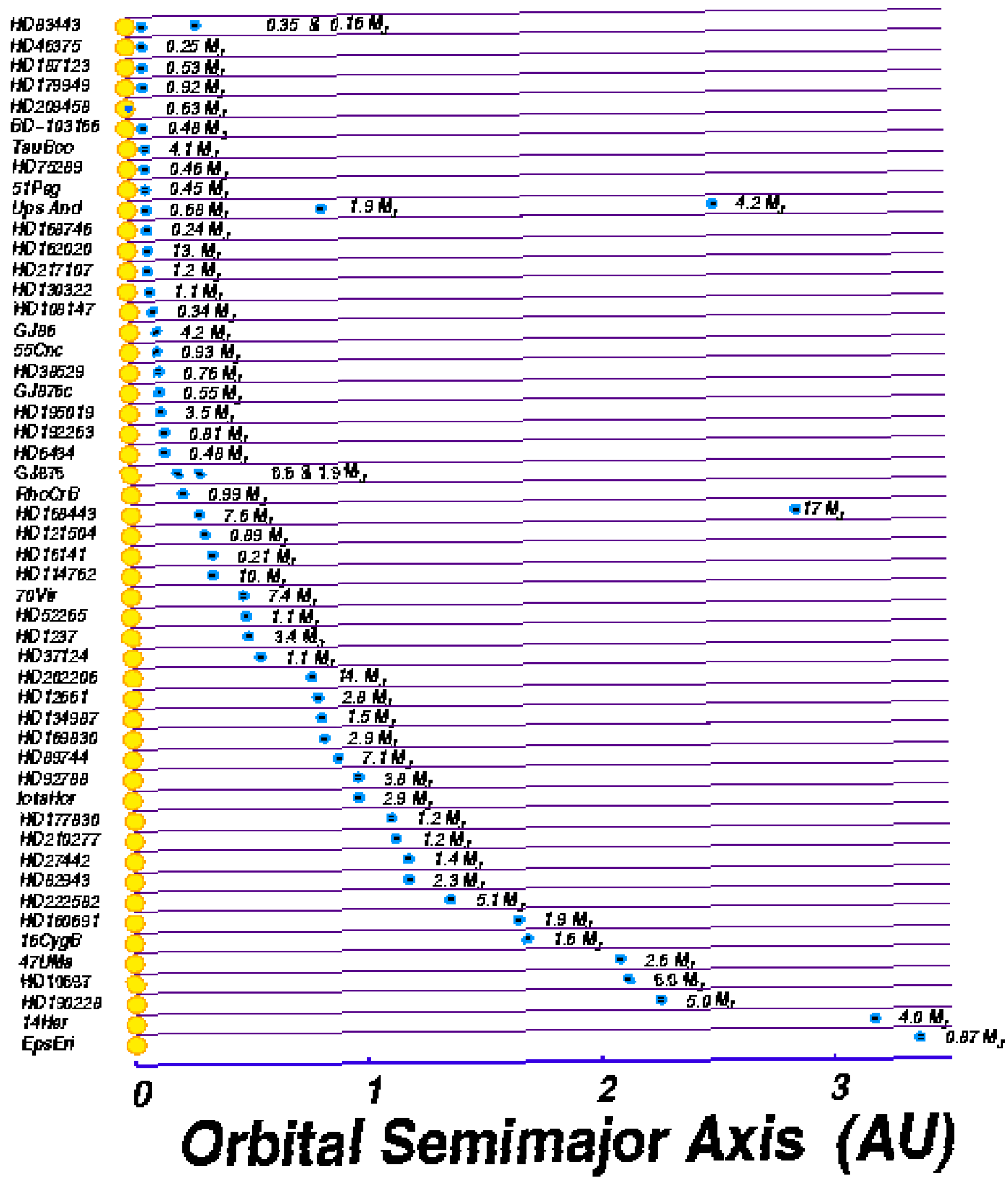
Today: the Catalog



Beyond the Catalog: Classification

- Mass, shape and alignment of orbit, composition and structure of atmosphere
- Distinguish between formation scenarios
- Planetary frequencies with age and metallicity
- Statistics of orbital elements and masses
- Planetary systems evolution (coplanarity, long−term stability)

FUTURE DISCOVERIES:

Establish the existence of Jupiter−LIKE planets around solar−type stars (F5 to K5), the signposts for the discovery of :

↓

Earth−Mass Planets

↓

Earths in the Habitable Zones: Earth−LIKE Planets

↓

Extra−terrestrial Life

Are They All Planets?

- **~1/5 have $M \sin i > 5\ M_J$**
- **Very different mass distributions for planet candidates and BD and binaries**
- **But, very similar orbital element distributions (especially, very high eccentricities)**
- **If orbits are seen face−on, many of them are not planets at all (Han et al. 2001)**
- **But, astrometry is still not sufficiently accurate (Pourbaix 2001)**

The GAIA Contribution

- Which stars? Solar−type dwarfs (F−G−K)
- How faint? $V < 13$
- How far away? 150−200 pc from the Sun
- Which class of planets? Giant planets (0.1−5 M_J), with periods up to twice the mission duration
- The available horizon includes ~$3x10^5$ stars, and thousands of giant planets might be detected and measured (Lattanzi et al. 2000)

Distance Range	*No. Stars*	Δa *(AU)*	*No. detections*
0–100 pc	~51,000	1.3 – 5.3	> 1600
100–150 pc	~114,000	1.8 – 3.9	> 1600
150–200 pc	~295,000	2.5 – 3.3	> 1500

Number of giant planets that could be revealed by GAIA, as function of increasing distance. A uniform frequency distribution of 1.3% planets per 1–AU bin is assumed.

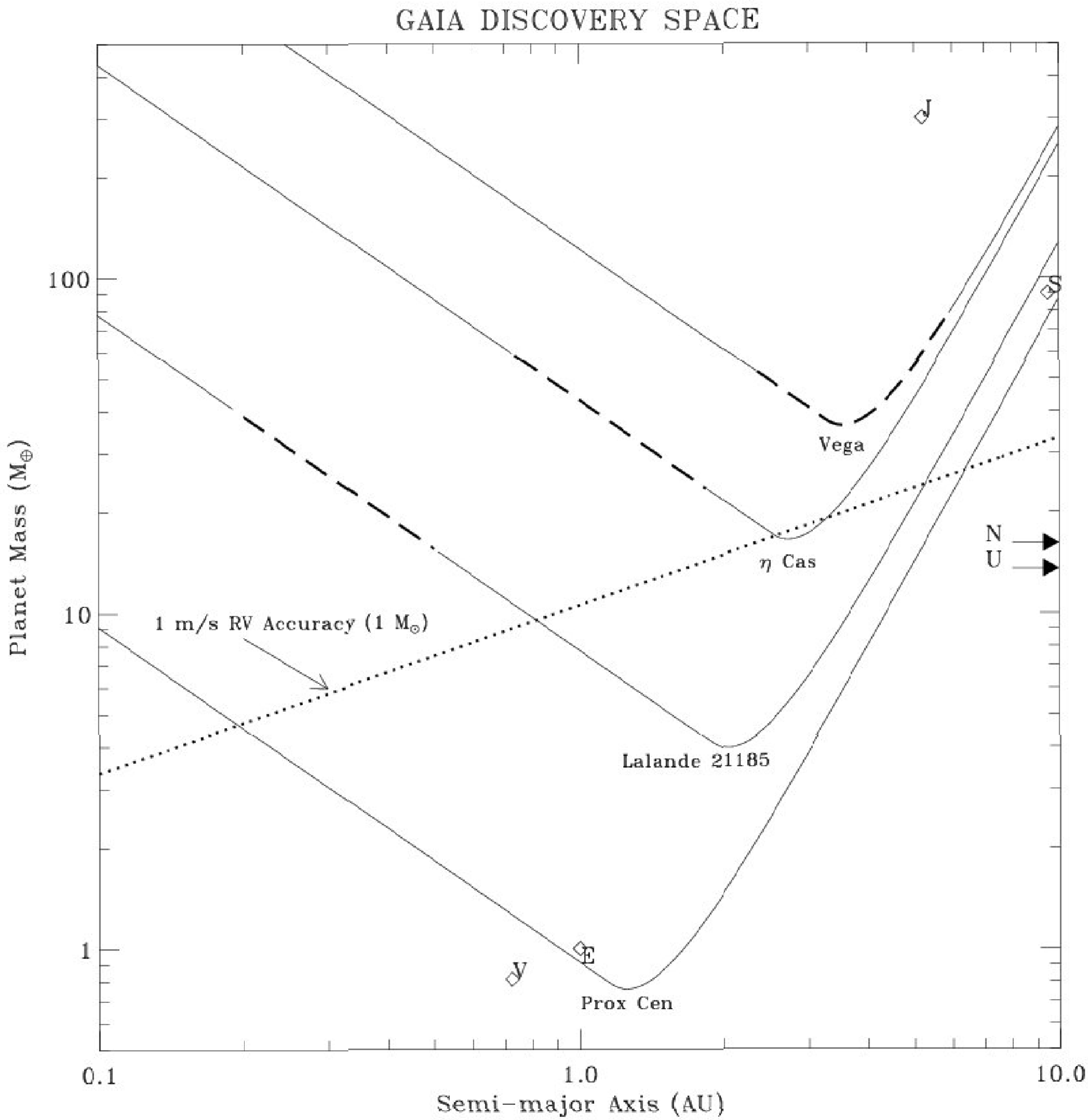
from Lattanzi et al. 1999

Fraction of Giant planets detected by GAIA with accurate orbital elements

Distance Range	*No. detections*	*No. accurate orbits*
0 –100 pc	**> 1600**	**> 640**
100–150 pc	**> 1600**	**> 750**
150–200 pc	**> 1500**	**> 750**

(From Lattanzi et al., 1999)

GAIA and the Closest Stars



GAIA and the Habitable Zones

- Today, only 2 candidate planets (14 Her and ε Eri) found by spectroscopy can be considered as actual ***Jupiter−signpost,*** orbiting at several AU from their parent stars.
- GAIA has the potential to discover **MANY** interesting systems, depending on actual frequencies, largely unknown to date.

..GAIA and Habitable Systems (1)

Theory provides us with two important concepts:

Habitable zone (liquid water) [Kasting et al. 1993] :

$$P_{HZ}\,(yr) = (M/M_{sun})^{1.75}$$

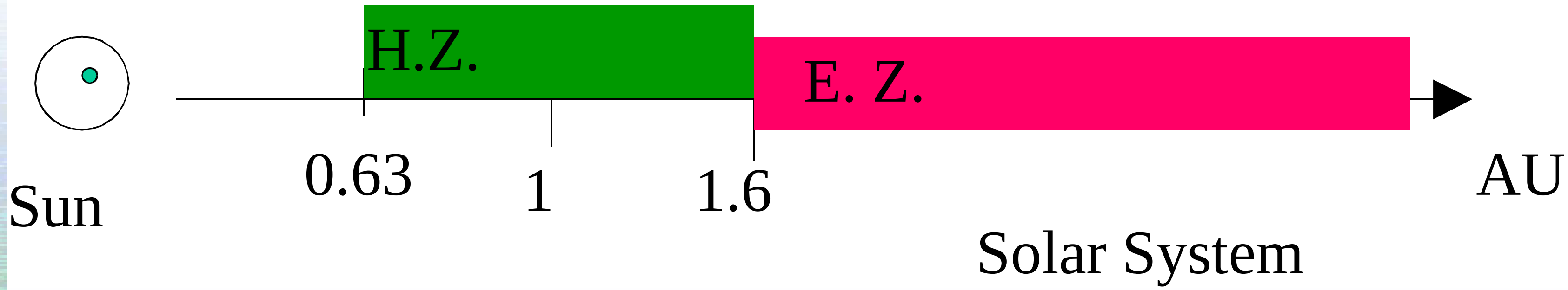
⇓

$$[P_{inner} = 0.5\,P_{HZ}\ ,\ P_{outer} = 2\,P_{HZ}\,]$$

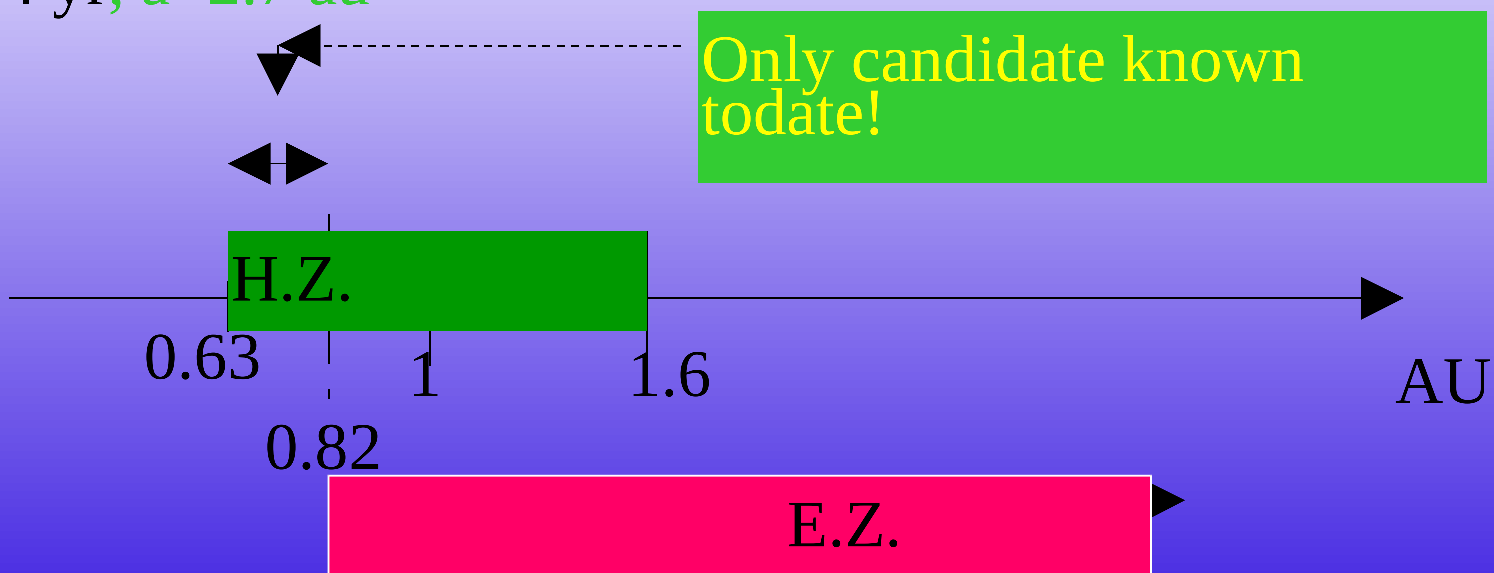
Exclusion zone [Wetherill 1996] :

$P_J < 6 * P_{earth}$ Earth does not form

GAIA and Habitable Systems (2)



For 14 Her (V=6.61): d=18.15 pc, M=0.98 M_{sun}, M_p = 3.3 M_J, P=4.4 yr, a=2.7 au



GAIA and the Planetary Systems

- For Planetary SYSTEMS having components producing S/N > 10, and on well−spaced orbits (P < 5 yr):
- GAIA will measure masses and orbital elements of each companion to < 1−10%
- GAIA will determine whether orbits are coplanar (or not!) with uncertainties of a few degrees
- The available horizon extends out to ~60 pc, or ~15 000 stars! (Sozzetti et al. 2001)

How can GAIA achieve this?

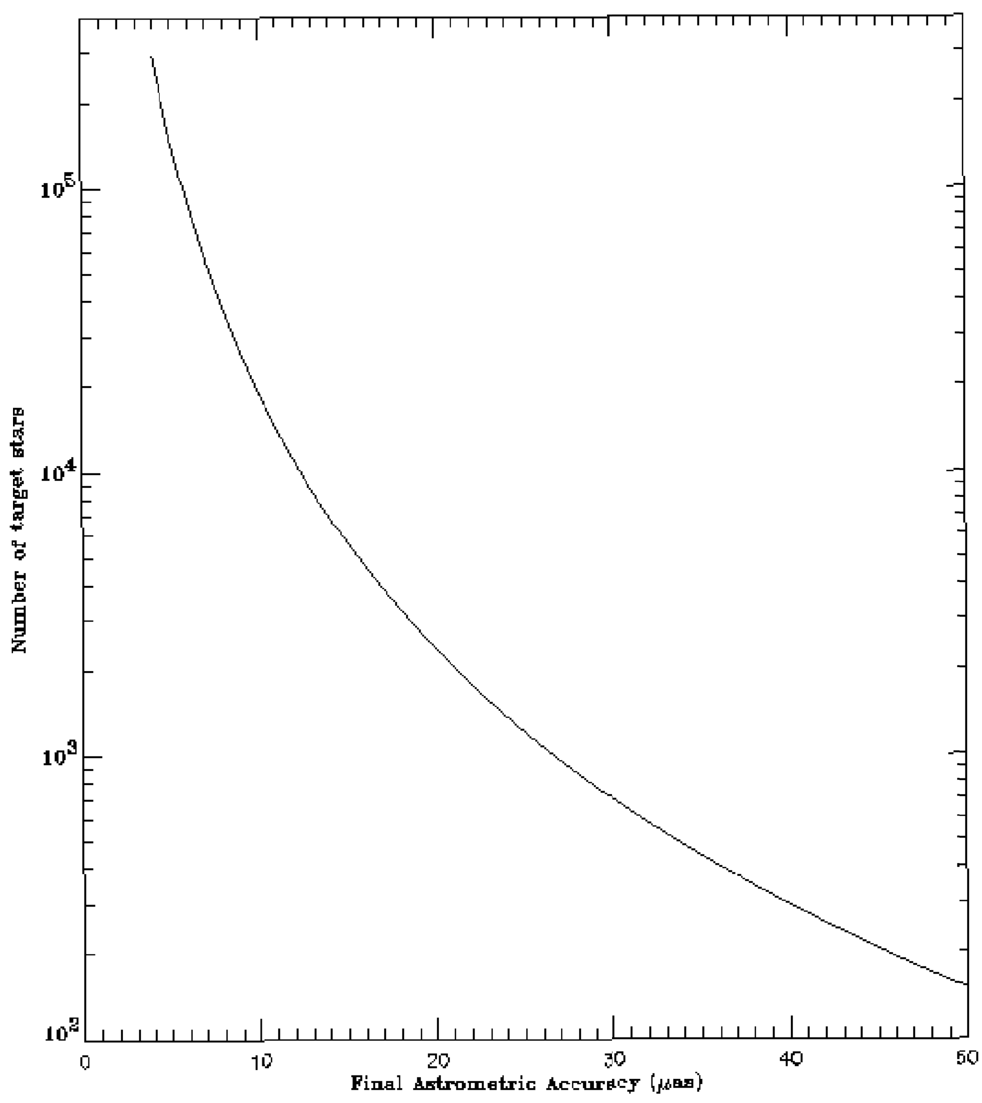
- ✔ Accurate payload design, in order to meet the requirements on astrometric accuracy
- ✔ Detailed and robust data analysis pipeline, for modeling the instrument performance as function of mission parameters, characteristics of planetary systems, and of all instrumental and astrophysical sources of systematic astrometric noise
- ✔ Joint usage of photometric, spectroscopic, and parallax data

GAIA Instrument

- **Must** meet the 4 μas final accuracy on bright objects ($V < 13$, 200 pc horizon, ~$3x10^5$ stars), contribution essentially due to systematics
- If final accuracy = 10 μas: ~$2x10^4$ stars
- If final accuracy = 20 μas: ~$2x10^3$ stars
- If final accuracy = 50 μas (DIVA): ~150 stars!

...and planets disappear from the GAIA Science Case...

Target stars as a function of astrometric accuracy



Modeling GAIA Performance

- ***Observable Model:*** **the science object position is expressed as function of all kinematic and dynamical parameters which contribute to significant motion of the stellar photocenter**
- ***Error Model:*** **takes into account all possible sources of instrumental and astrophysical systematic errors, and their correlations**
- ***Estimation Process:*** **robust statistical tools for the residuals analysis (χ^2 test, Fourier statistics and periodograms); linearized iterative methods for (multiple) orbital fits; global search and optimization strategies of starting guesses (double−blind tests)**

Using the wealth of GAIA data

- ***Photometry:*** **determines transits for close−in giant planets, accounts for intrinsic variability**
- ***Radial Velocity:*** **determines the third component of the stellar motion, finds spectroscopic binaries**
- ***Preliminary parallax:*** **determines the distance to very high accuracy within 200 pc**
- **ALL these data combined help select the best candidates for successive and final processing of the data**