Detection and characterization Of Giant Planets Combining Astrometry, Radial Velocities and Transits: The GAIA Potential

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1 - INAF - Astrophysical Observatory of Turin

Toliman – Finding Earth Twins within 10 pc

Roma, 2018/11/19

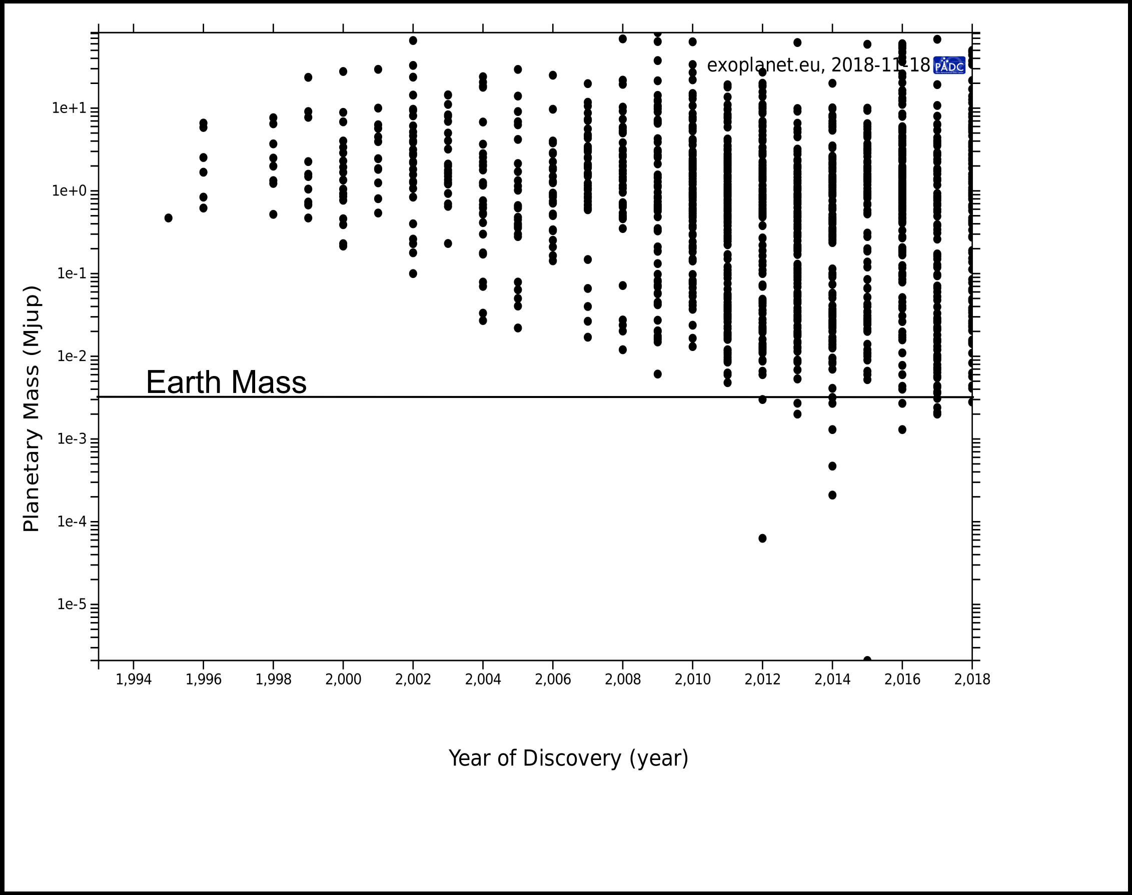
Comparative Planetology

Rapidly evolving field

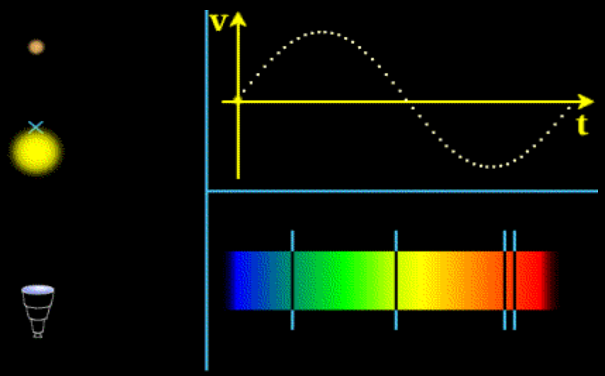
The number of discovered planets changes every day.

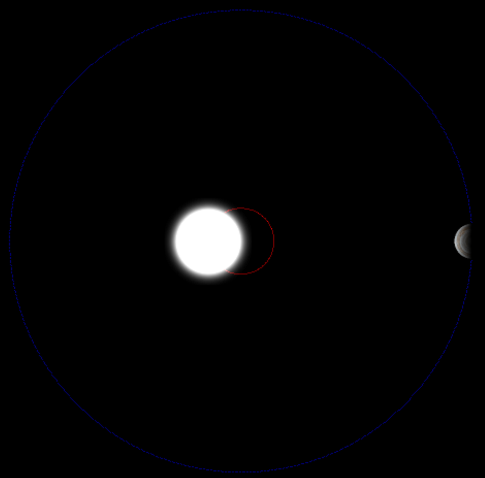
Now we know 2896 planetary systems / 3885 planets / 645 multiple planet systems.

The 90% of the known planets was discovered using an indirect method of detection.



The indirect methods of detection





Radial velocities

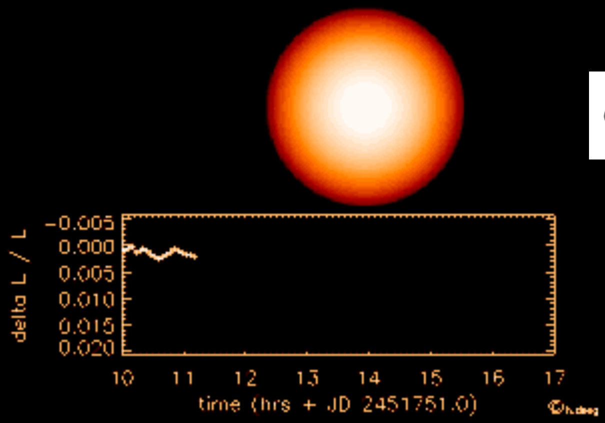
Astrometric method

Cons: Minimum Mass

$$M_{planet} \sin i$$

Cons: Volume limited

$$\varsigma = (M_p/M_\star) \times (a_p/d)$$



Transit method

Cons: Transit probability

$$Probability \simeq \frac{R_\star}{a}$$

When a planet transits its star:
a treasure trove

The planet becomes a target for **structure, chemistry, and dynamics of atmospheres** characterization

Figure from Seager (2010), Exoplanet Atmospheres

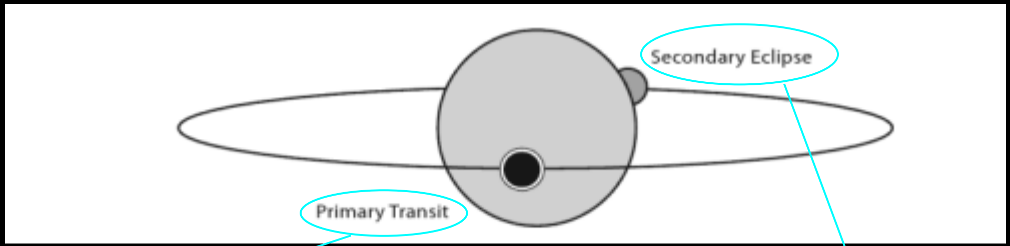
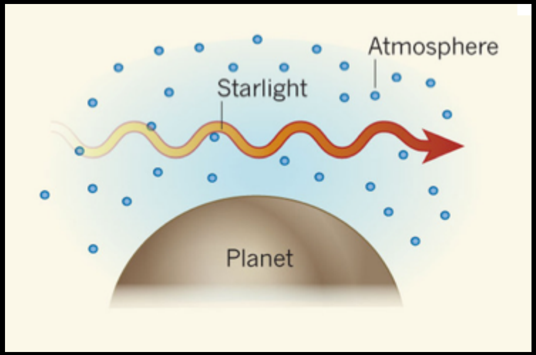


Figure from Deming, Nature, 2010



The secondary eclipse allows direct measurement of the planet's radiation → planet's temperature and signs of cloud formations

Atomspheric characterization via transmission spettroscopy

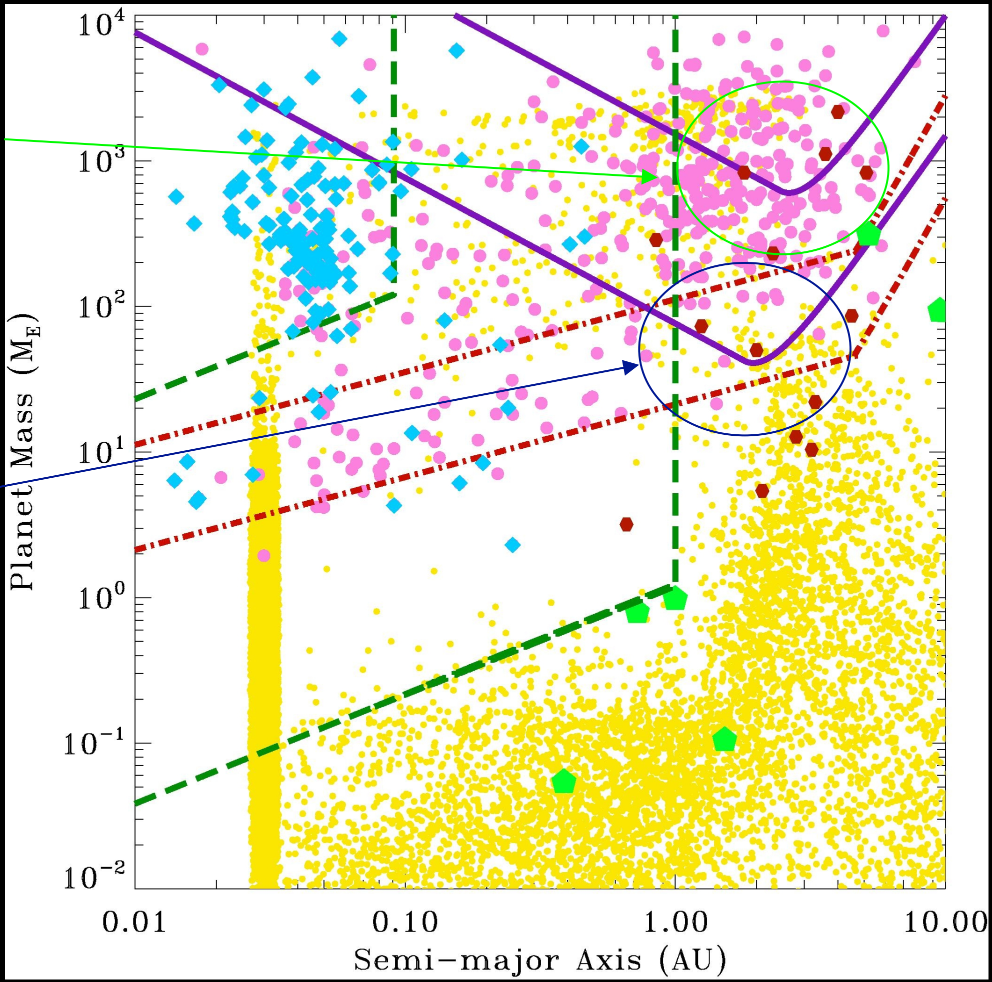
Can GAIA contribute?

Gaia: a 20 μas machine!

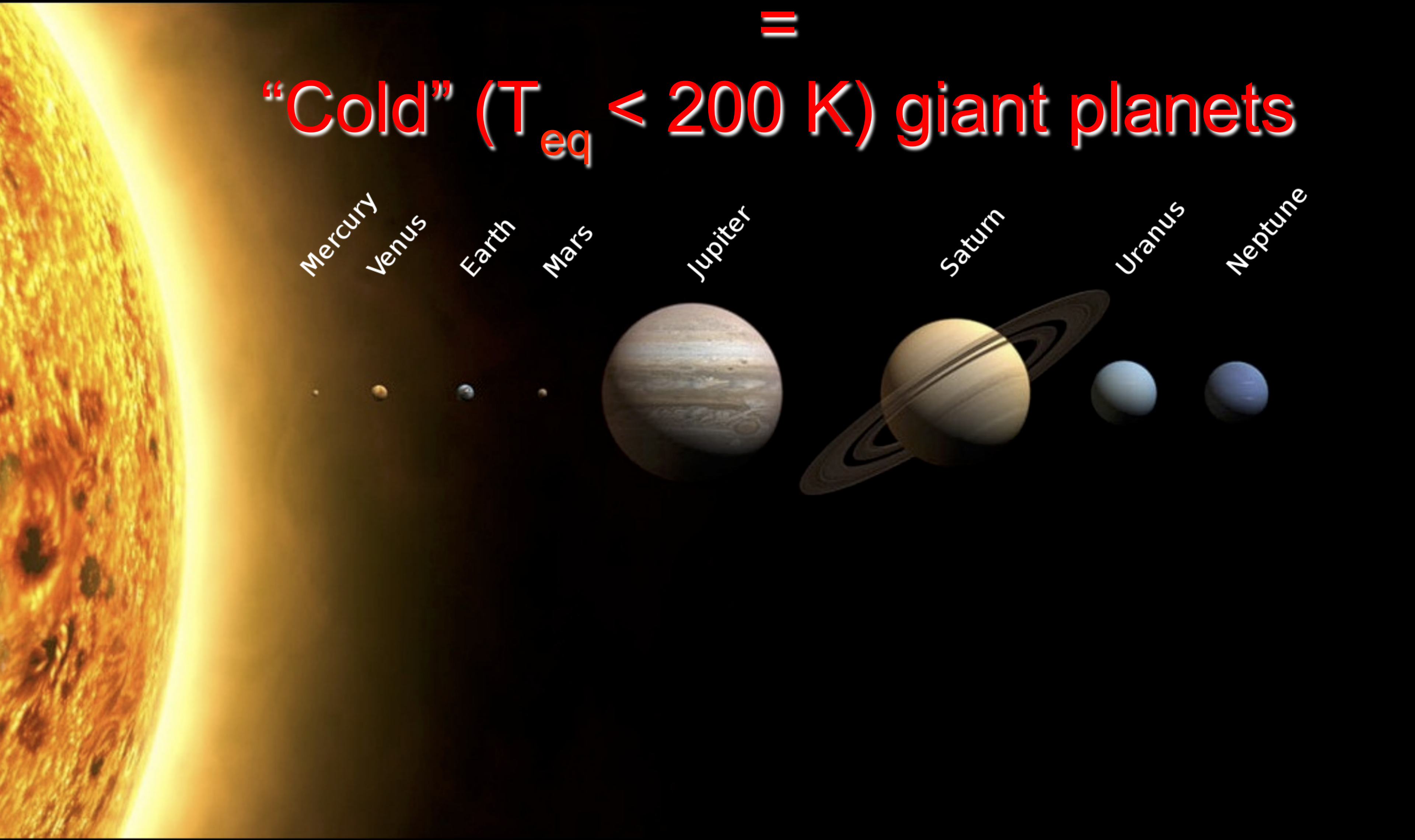
2-3 M_J planets at 2<a<4 AU are detectable out to ~200 pc around solar analogs

Saturn-mass planets with 1<a<4 AU are measurable around nearby (<25 pc) M dwarfs

Unbiased, magnitude-limited planet census of hundreds of thousands stars



Long-period (> 1 yr) giant planets
=
“Cold” (T_{eq} < 200 K) giant planets



They constitute a valuable sample for comparative studies with those of the outer planets of our Solar System.

Gaia detection probabilities

M dwarfs starcounts to G=20 within 100 pc: ~500k stars

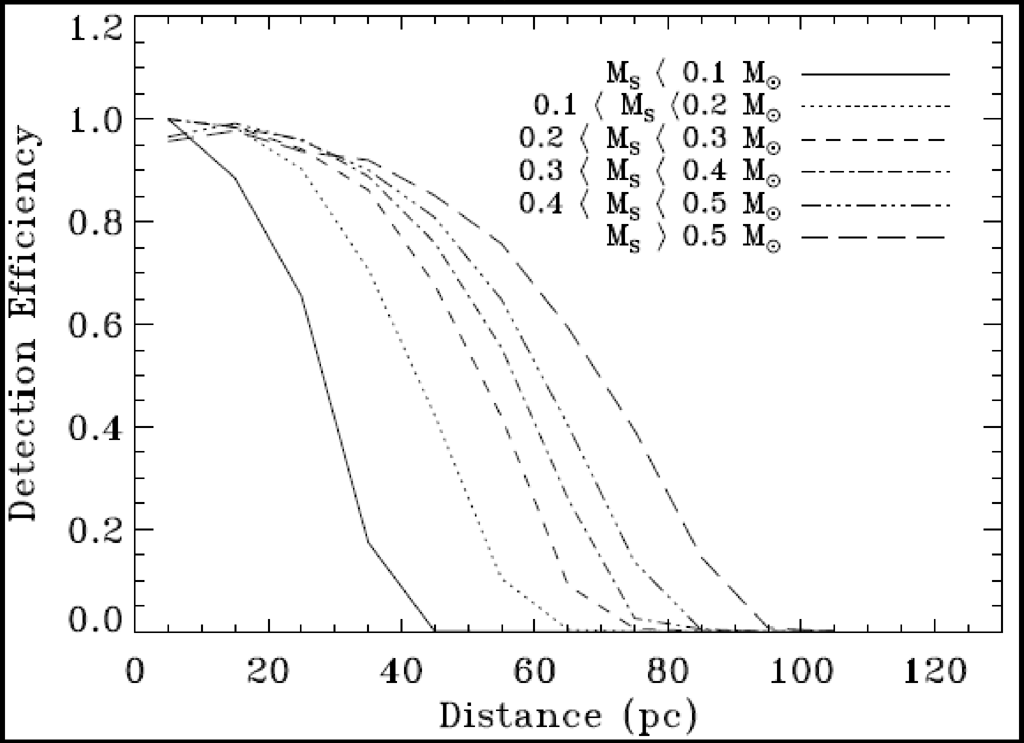
Simulated sample from the Besancon Galaxy Model

~ 2600 giant planets around M dwarfs at d < 100 pc

~ 100 giant planets around M dwarfs at d < 33 pc

Astrometric signature

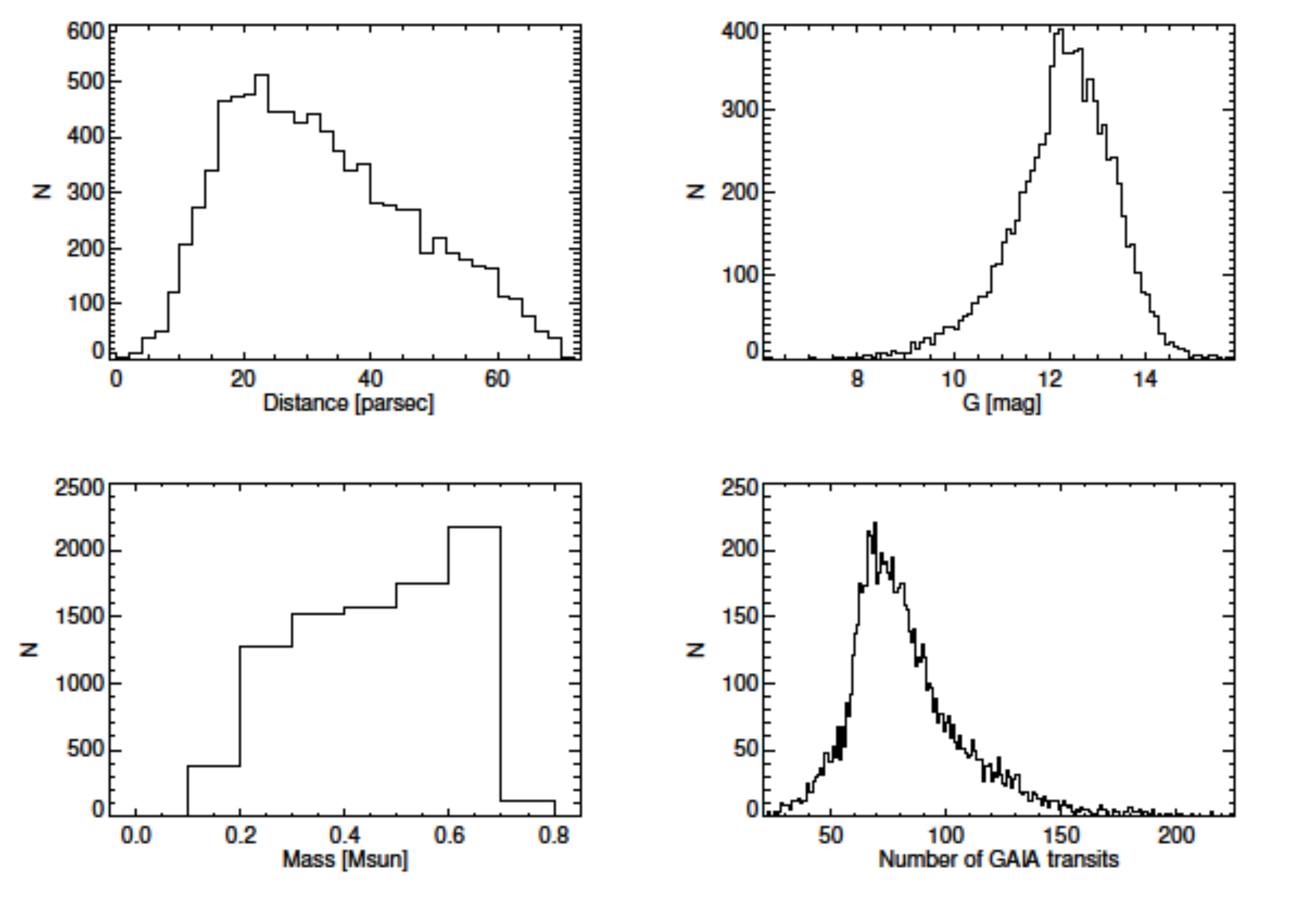
$$\varsigma = (M_p/M_\star) \times (a_p/d)$$



Sozzetti, Giacobbe et al. 2014

Focusing on bright M dwarfs
Measuring (Transiting) Systems Configurations
Simulation setup

Test on the Lepine & Gaidos (2011) sample



8793 M dwarfs (M0-M8)

1 $M_{jupiter}$

I =90°

0.2 < P < 5 years

0 < T < P years

0 < e < 0.6

7μas < a < 4970μas

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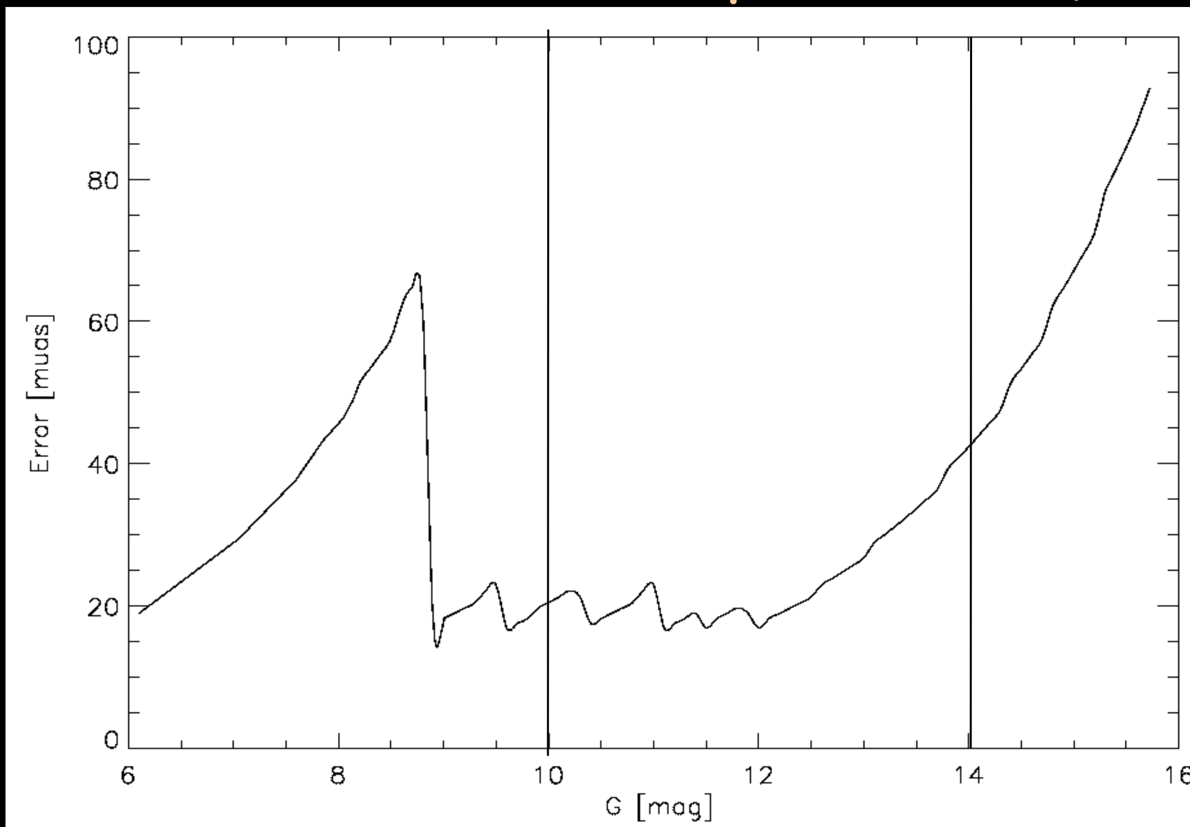

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The adopted error model (Sozzetti et al. 2014) is still consistent with the expected **end of mission performance (Lindegren et al. 2018)**

A Hybrid DEMCMC method for orbit reconstruction

Why do we need this?

-Fitting orbits of exoplanets: high-dimensional space, non linear parameters...

-Brute-force multi-dimensional grids: eventually will succeed, but very time consuming, particularly in the economy of the Gaia pipeline

-Some options (periodograms + local minimization) are not applicable to Gaia

The Differential Evolution Monte Carlo Markov Chain (DEMCMC) technique has the advantage of being well suited to high-dimensional parameter spaces.

Analysis tool
A Hybrid DEMC method

Orbit described by P, T, a, e, i, ω, Ω (Campbell elements)

Non linear

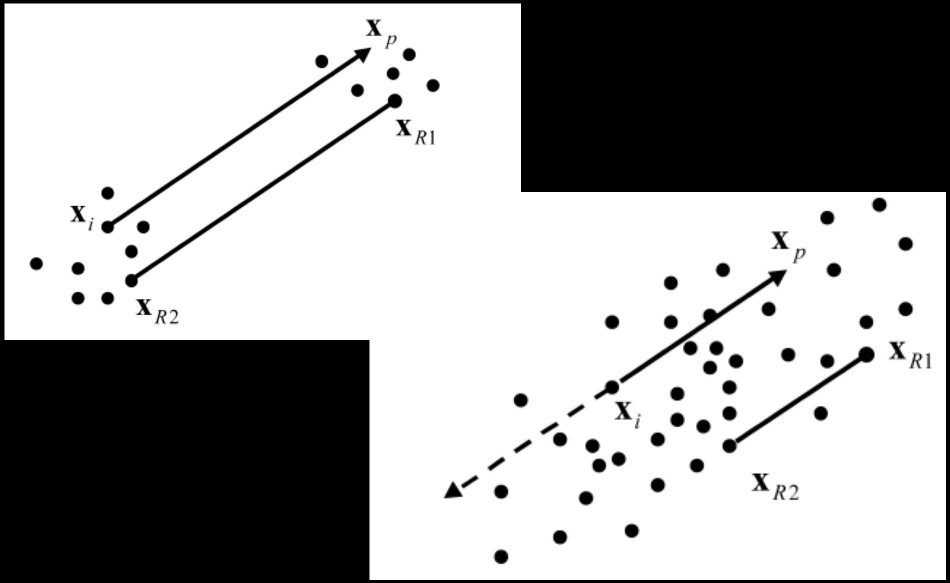
Orbit described by P, T, e, A, B, F, G (Thiele-Innes elements)

Non-Linear Linear

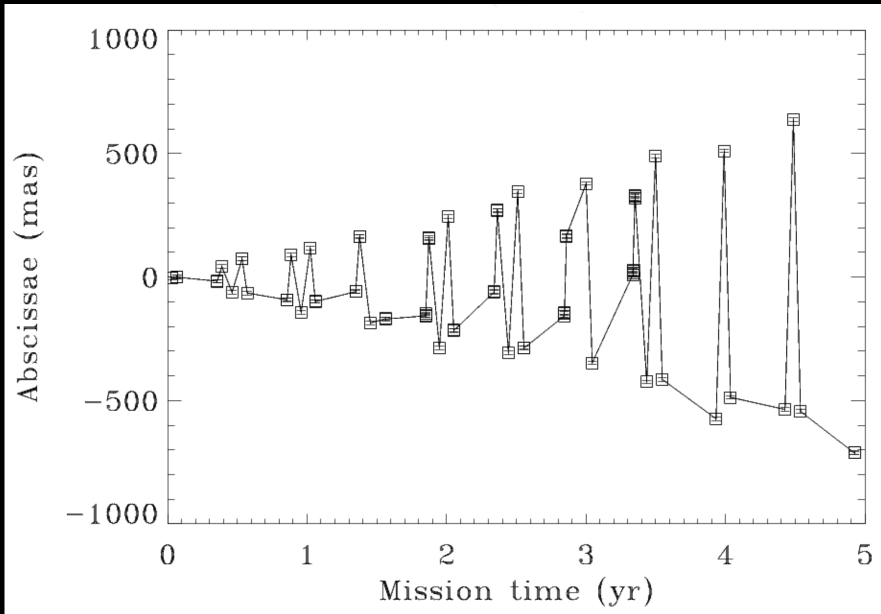
Numerical solutions of a system of linear equations

Integrated Markov Chain Monte Carlo methods with the genetic algorithms

Differential Evolution (DE) is a simple genetic algorithm for numerical optimization in real parameter spaces



GAIA + RV Follow-up



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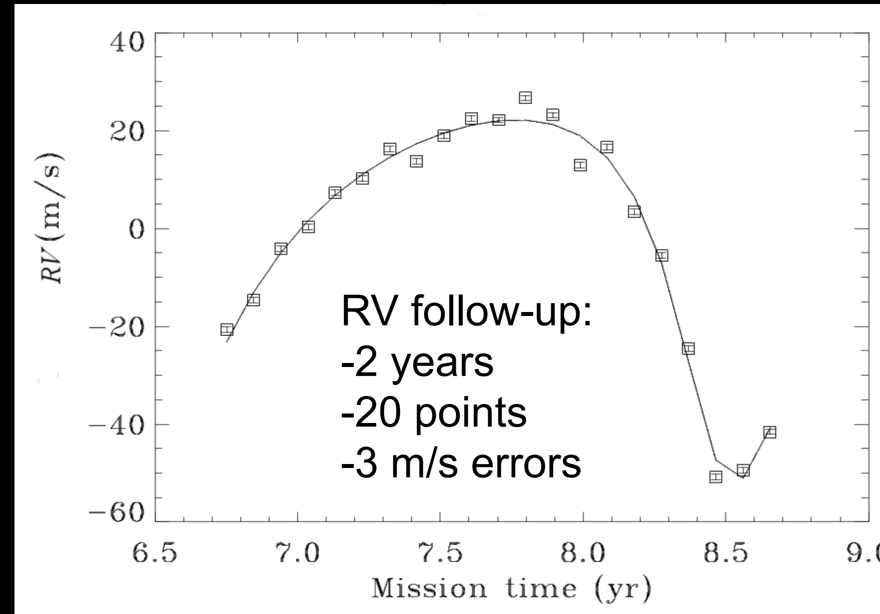
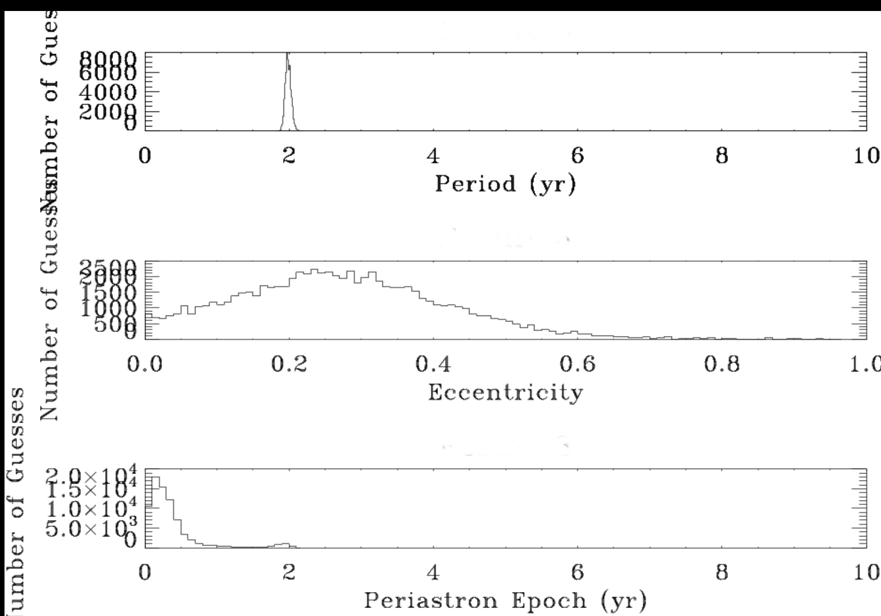
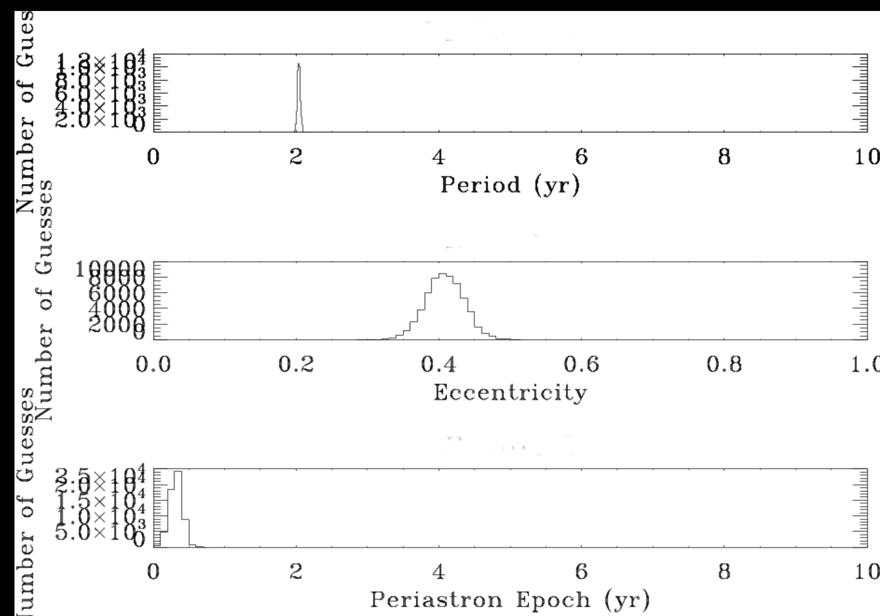
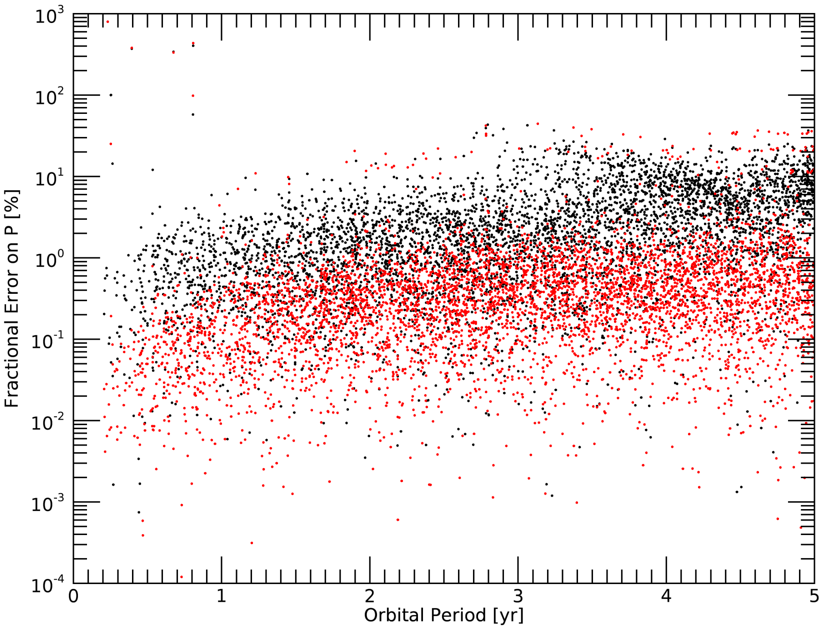
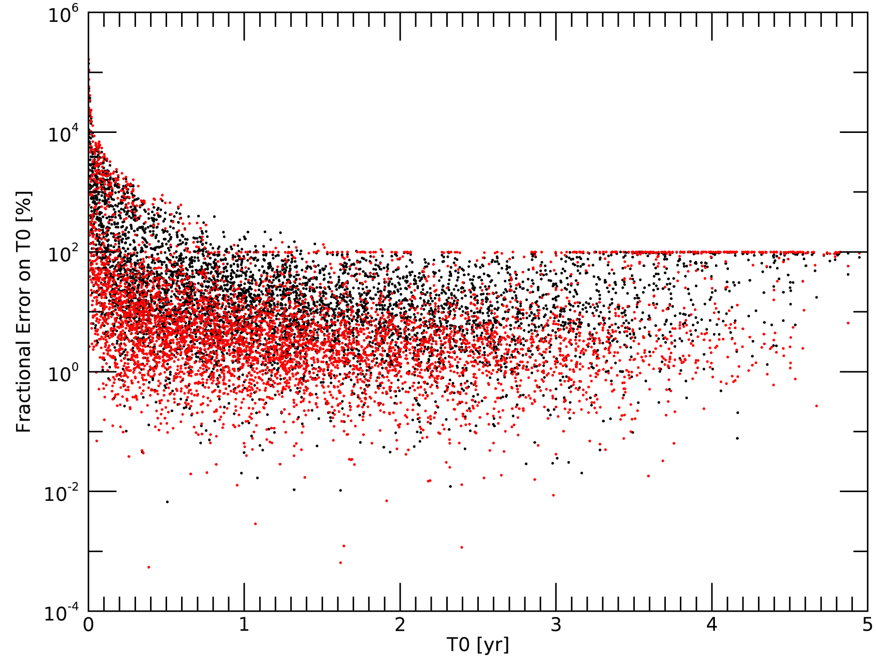
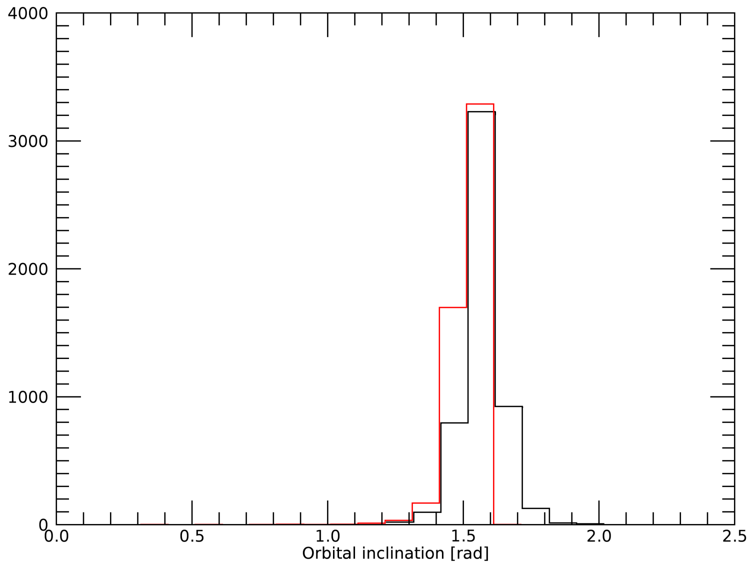


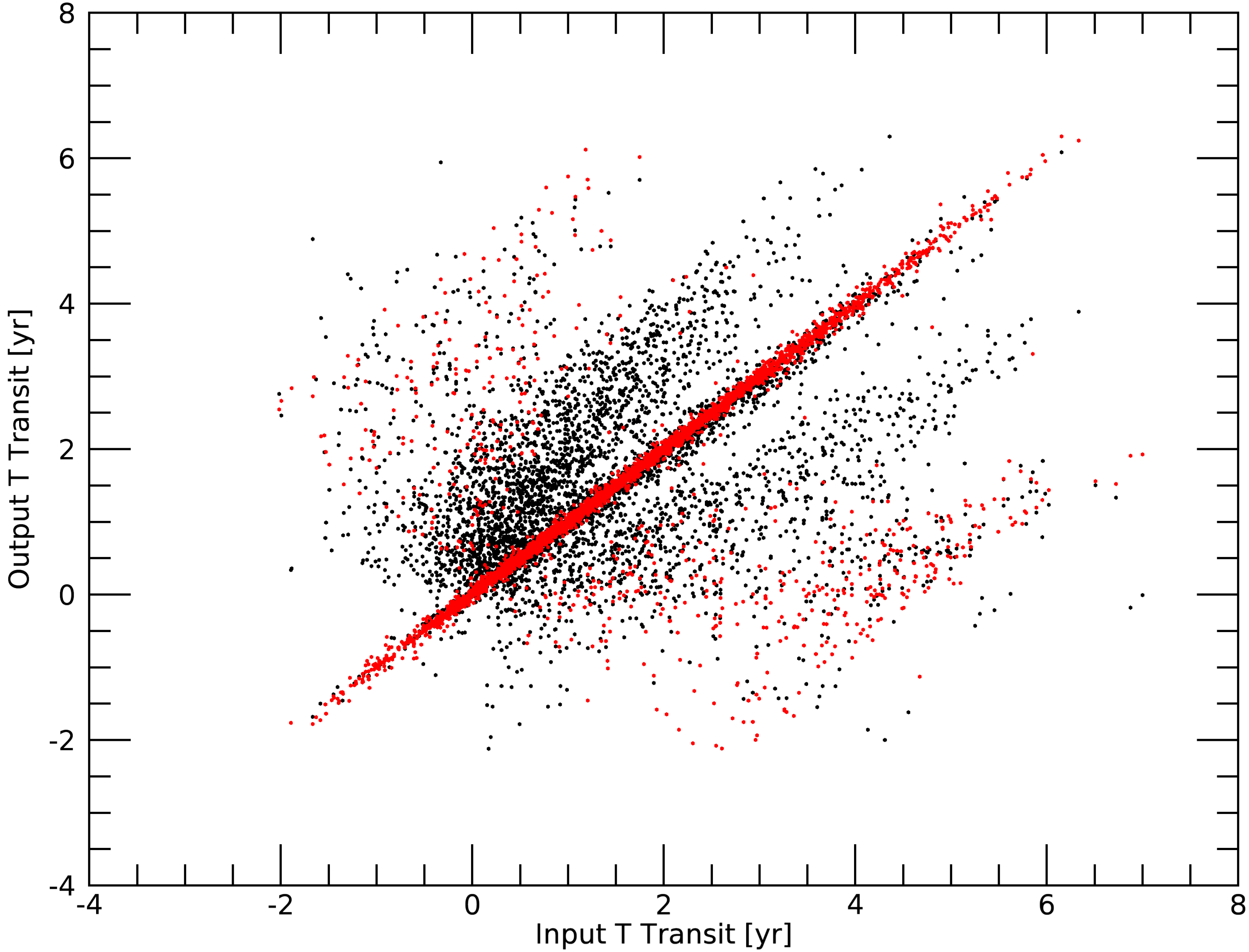





Fractional Error on P [%]
Orbital Period [yr]
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
0
1
2
3
4
5


Fractional Error on T0 [%]
T0 [yr]
10^6
10^4
10^2
10^0
10^-2
10^-4
0
1
2
3
4
5


4000
3000
2000
1000
0
0.0
0.5
1.0
1.5
2.0
2.5
Orbital inclination [rad]



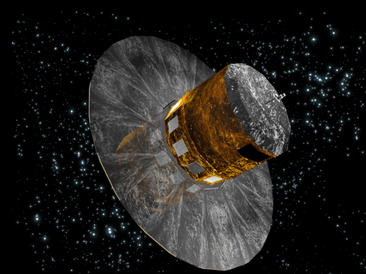
~10[days] uncertainty on the Transit Epoch in 0.1 < P < 5 yrs Period range

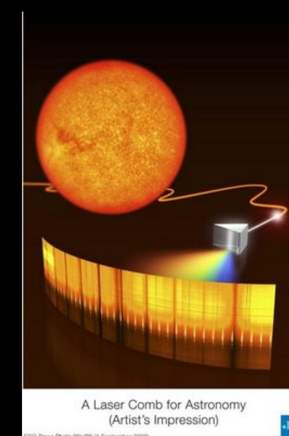
Focusing on the synergies

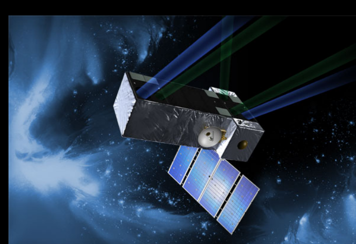
WHY?

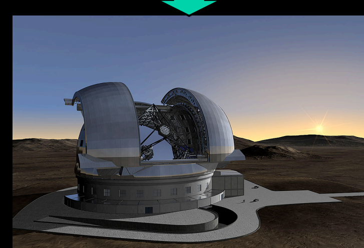
Big opportunities for planet characterization with the bright sample of nearby stars

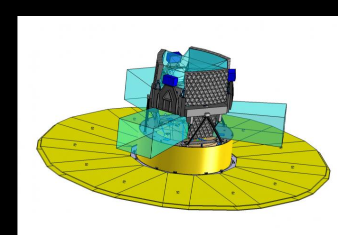
The sample of the nearest (d < 25–30 pc) and bright (J < 10) Mdwarfs is amenable to combined studies with a wide array of observational techniques



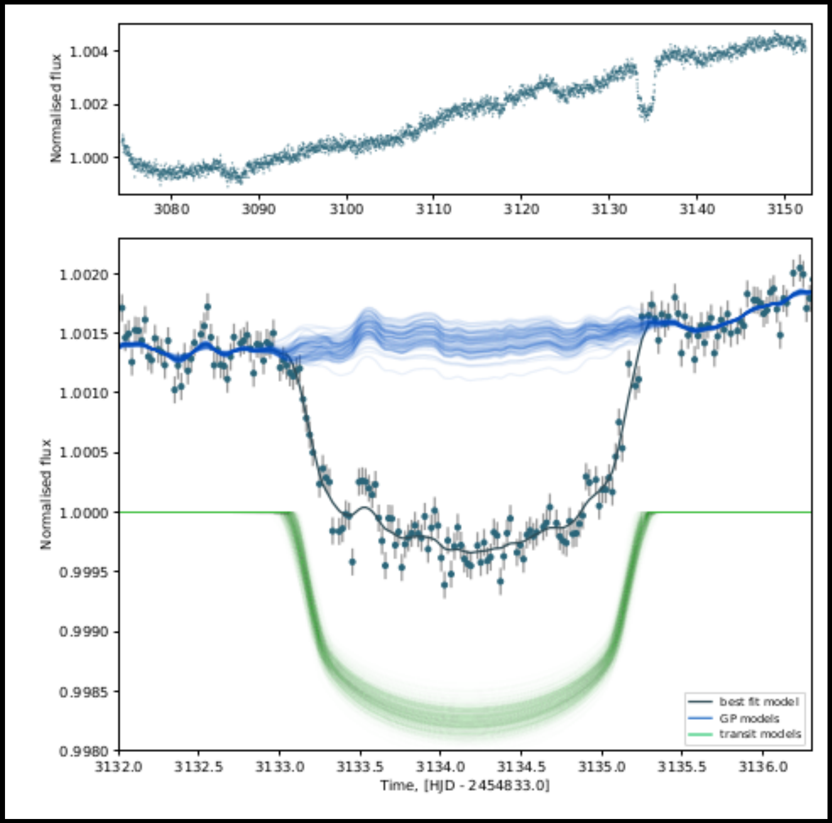








EPIC248847494
The longest period transiting planet candidate from K2
Giles et al. 2018



P ~ 10 yrs

Radius = 1.1 $R_{jupiter}$

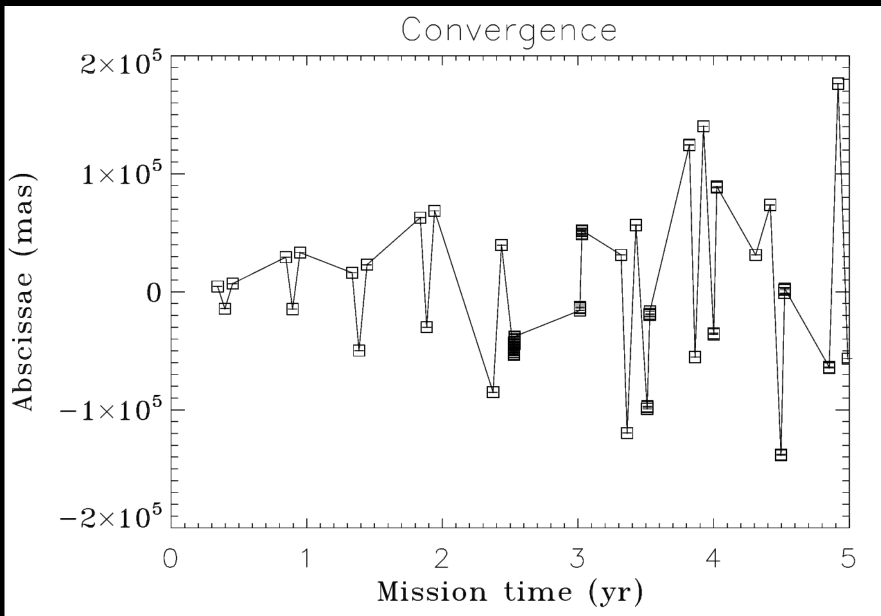
Mass ~ 1 $M_{jupiter}$ from 1 yr RV campaign with CORALIE @ ESO

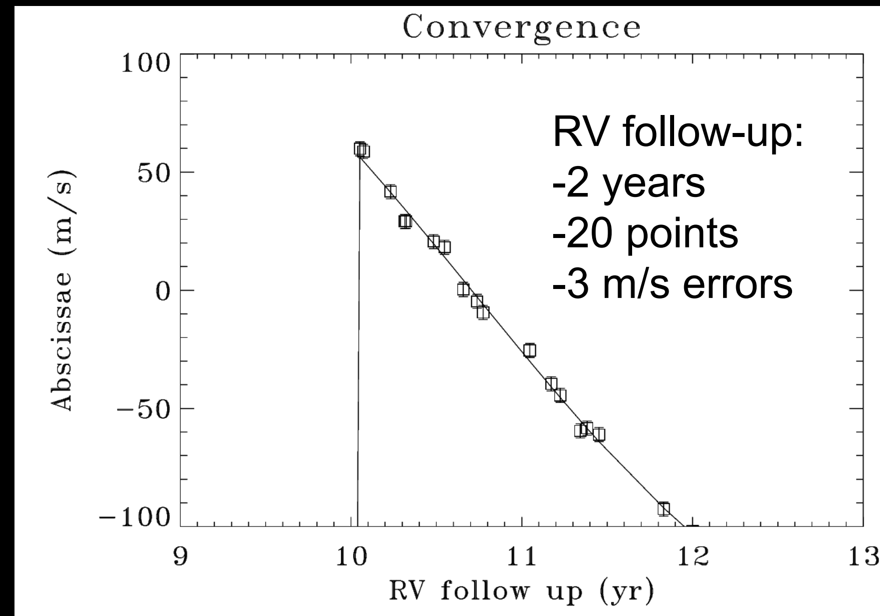
I = 90°

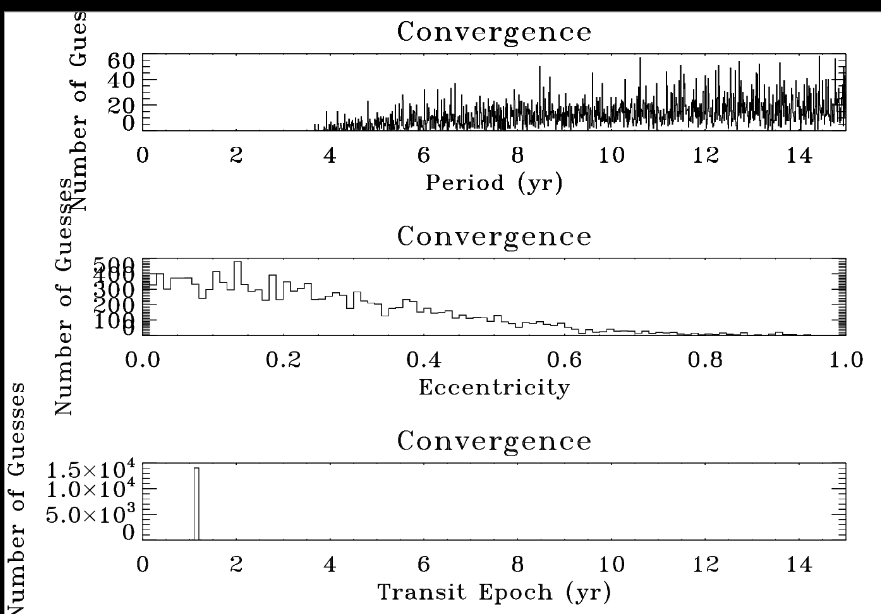
eccentricity ???

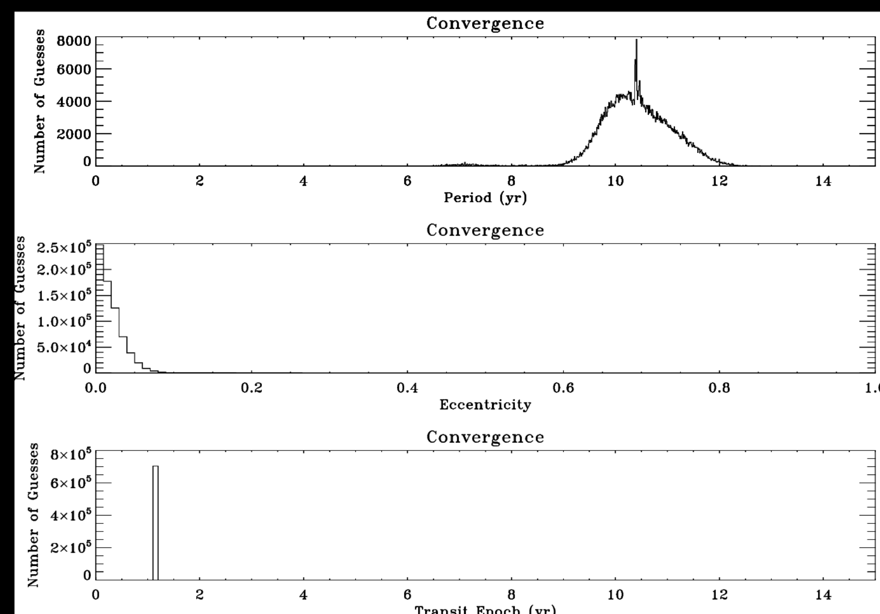
Host star:
0.9 M_{sol}
2.7 R_{sol}
Distance = 560 pc

GAIA + RV Follow-up









Summary

We investigated the impact of Gaia astrometry in the exoplanets field and the potential synergies between Gaia astrometry and other ground-based and space-borne programs, focusing on:

a) the potential for Gaia to precisely determine the orbital inclination, which might indicate the existence of transiting long-period planets;

b) the ability of Gaia to carefully predict the ephemerides of transiting planets around M stars for photometric and spectroscopic follow-up characterization.

c) the ability of Gaia, combined with RV, to fully characterize the orbit of long period transiting planets.

Preliminary results are encouraging!