Finding Hot-Jupiters by *Gaia* photometry using the Directed Follow-Up strategy

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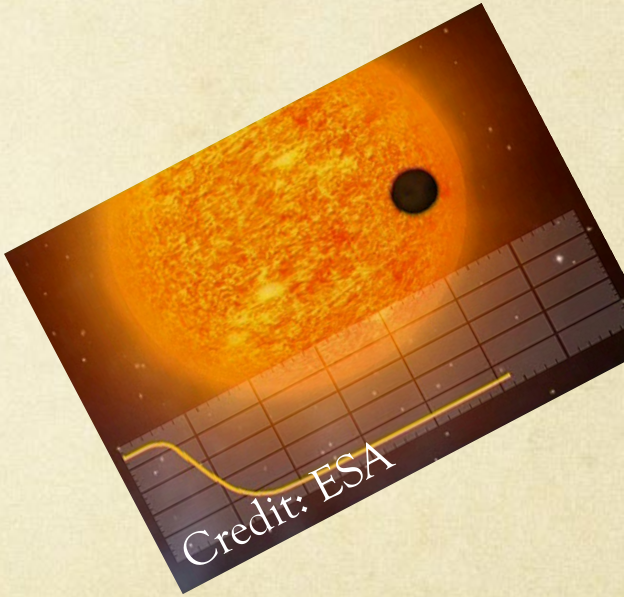
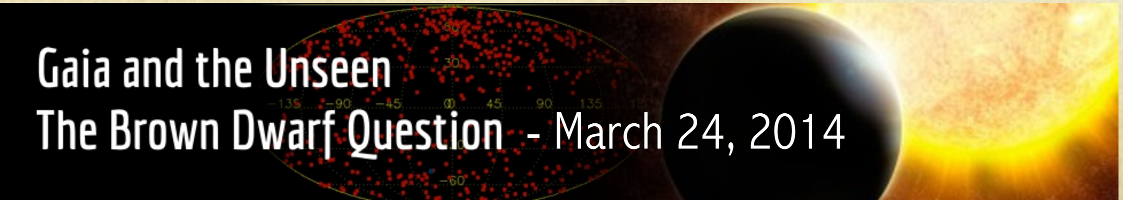
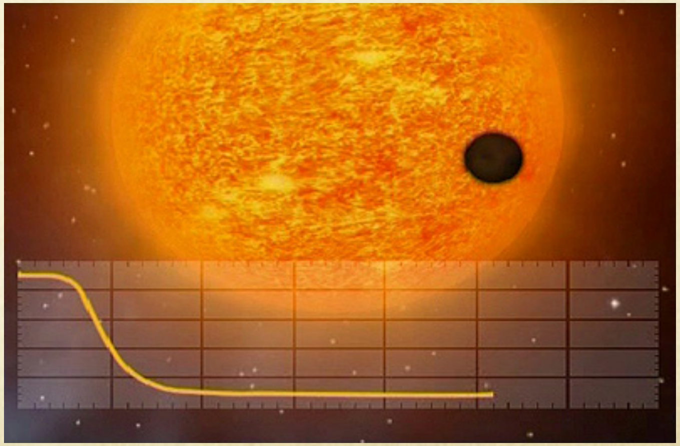




Transiting Exoplanets *(especially Hot-Jupiters)*: what can they tell us?

1. Radius of the planet
2. Orbital inclination and Mass when combined with radial velocity
3. Spin-Orbit (Mis)alignment angle
4. Albedo (reflected light)
5. Atmospheric spectral features



Transiting Exoplanets: The challenge

In order to detect 1 typical HJ we have to observe thousands of stars with full coverage

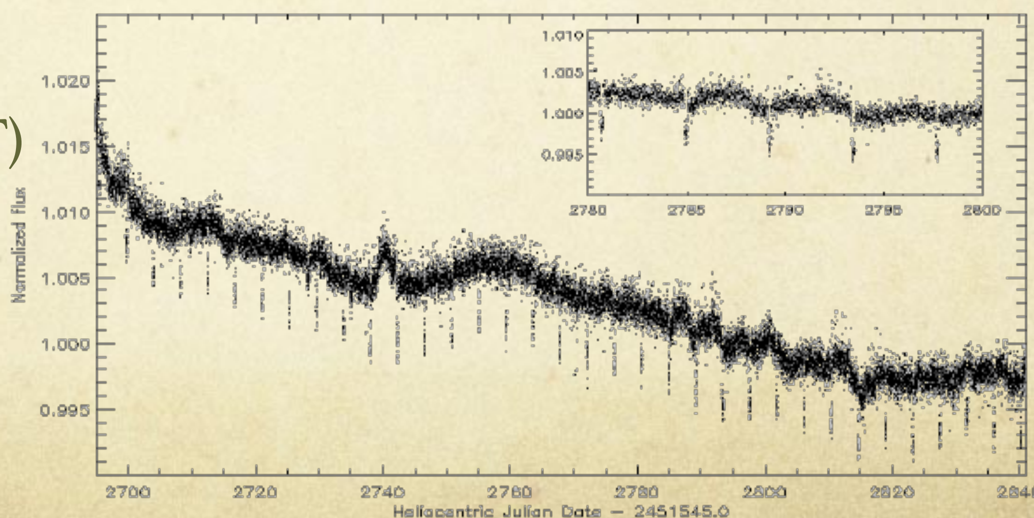
Transit detection is a bit like playing the slot machine:

- Observe many stars
- Frequent observations

Dedicated surveys (COROT)

High-cadence

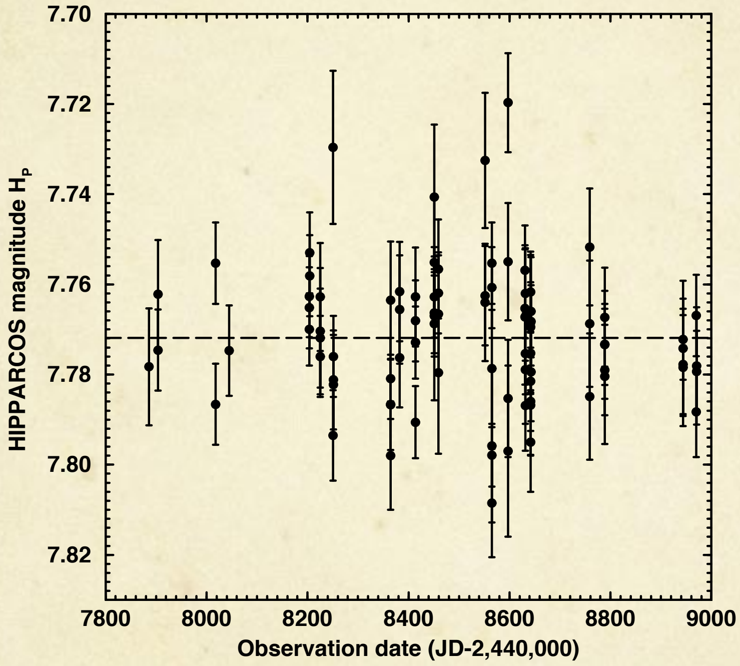
Dense fields



Deleuil et al. (2008)

Transiting Exoplanets: Low-cadence surveys

Hipparcos Epoch photometry - HD209458



Robichon & Arenou (2000)

“Hipparcos Catalog does not represent a likely place to detect planets in the absence of other information” (Jenkins et al. 2002)

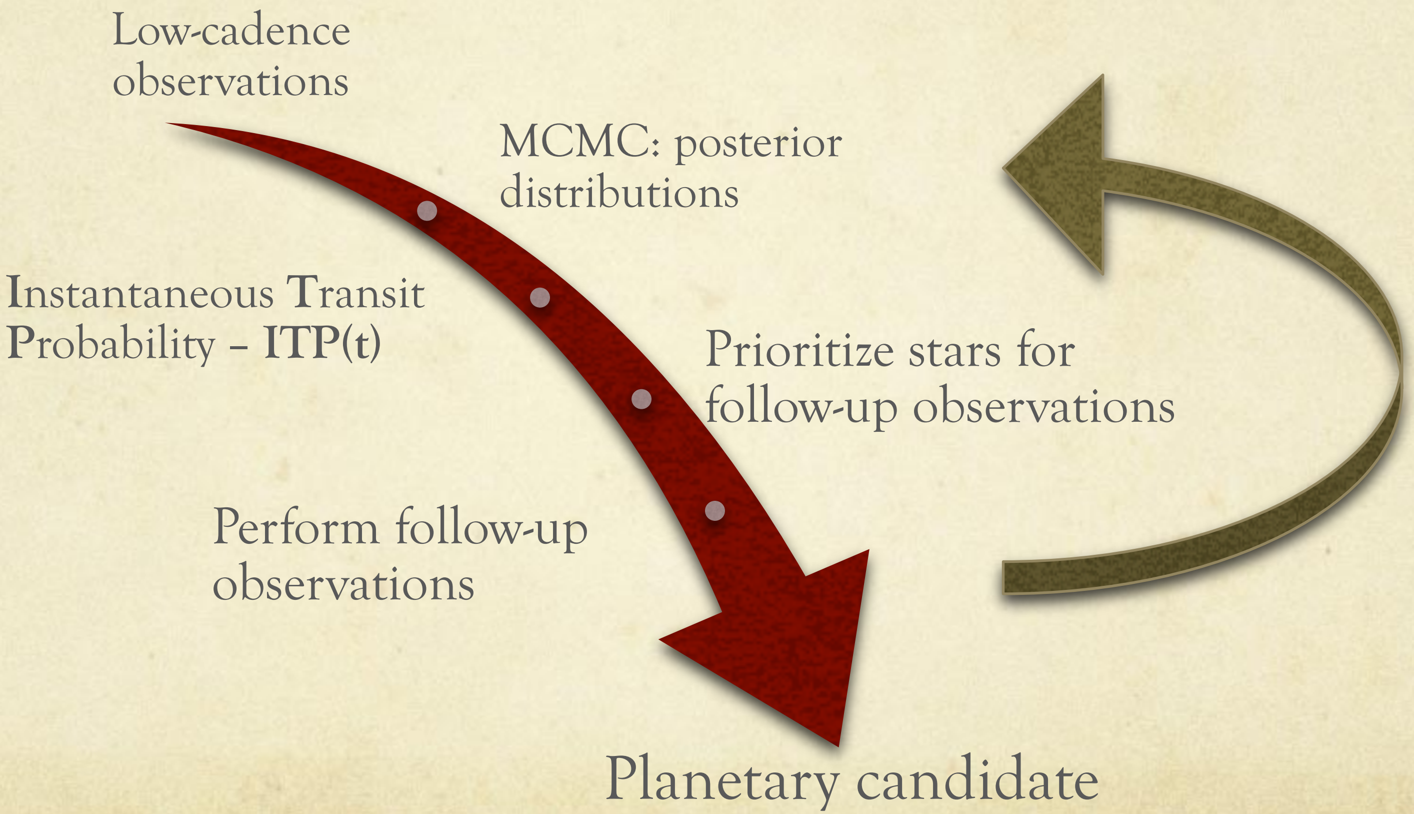
Directed Follow-Up *(DFU)* strategy for low-cadence surveys

Sampled transits provide *some* information about the hypothetical transit, if it exists.

Using MCMC we can present this scarce information as a Probability Distribution Function

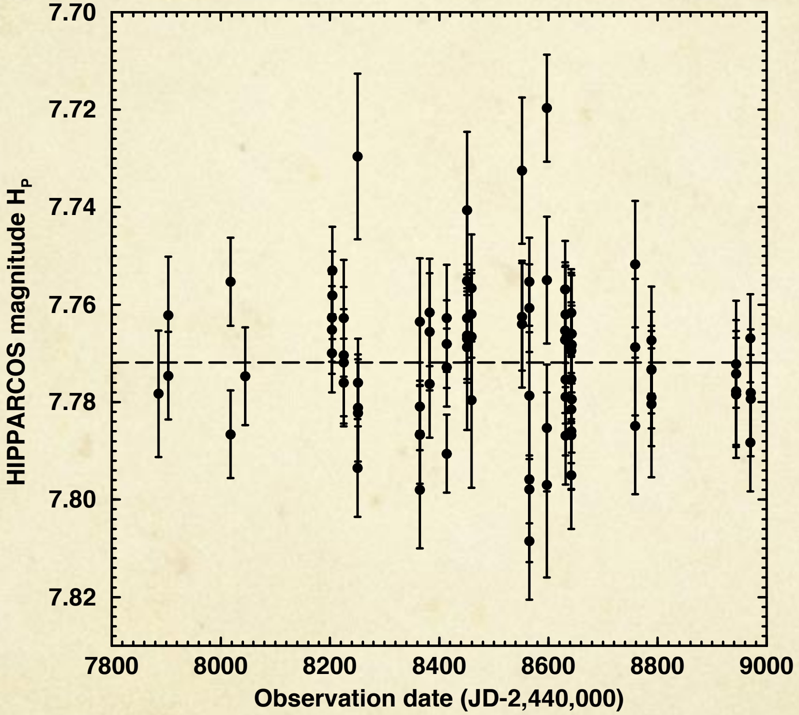
"Data don't make any sense,
we will have to resort to statistics."

Directed Follow-Up strategy for low-cadence surveys



DFU Application to *Hipparcos* Epoch Photometry – HD 209458

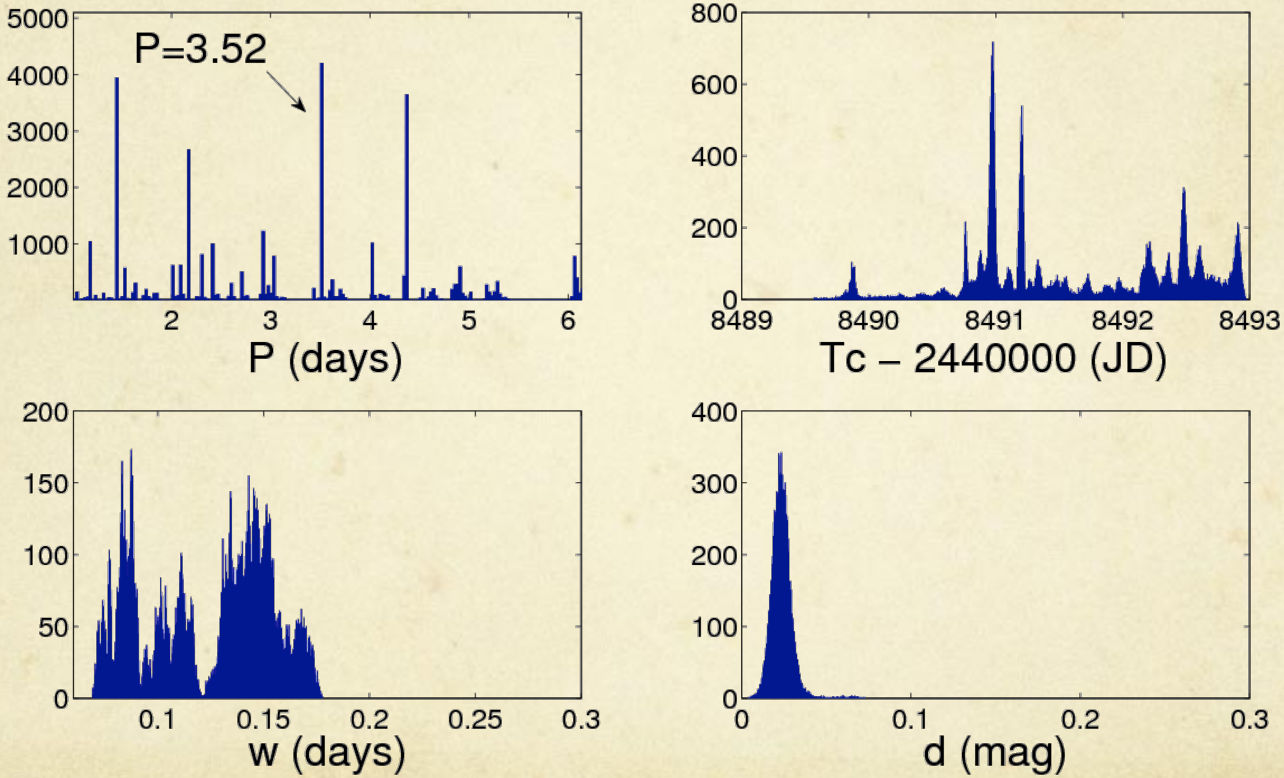
Low-cadence *Hipparcos* observations



Robichon & Arenou (2000)

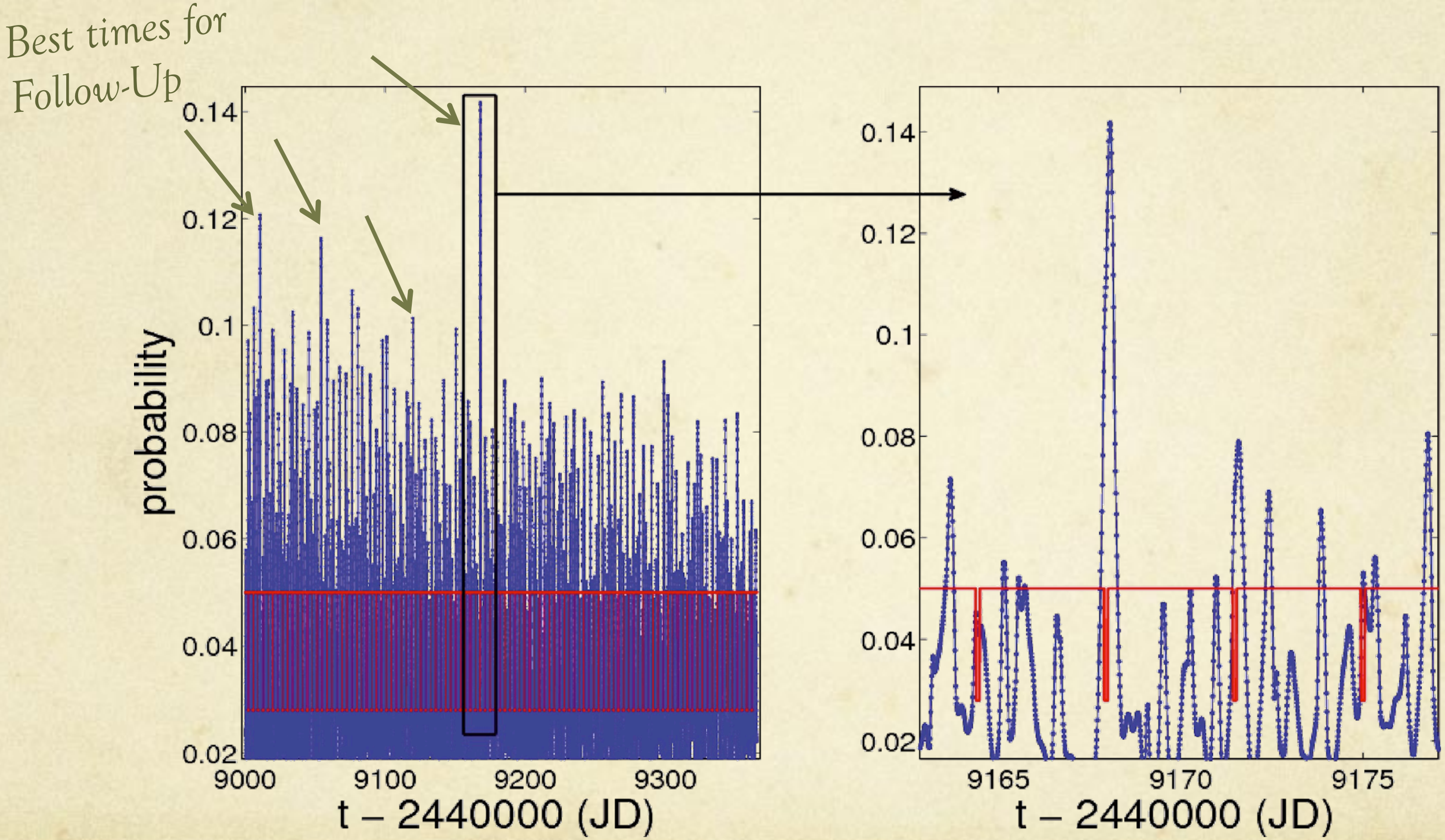
DFU Application to *Hipparcos* Epoch Photometry – HD 209458

MCMC – posterior distributions



Dzigan & Zucker (2011)

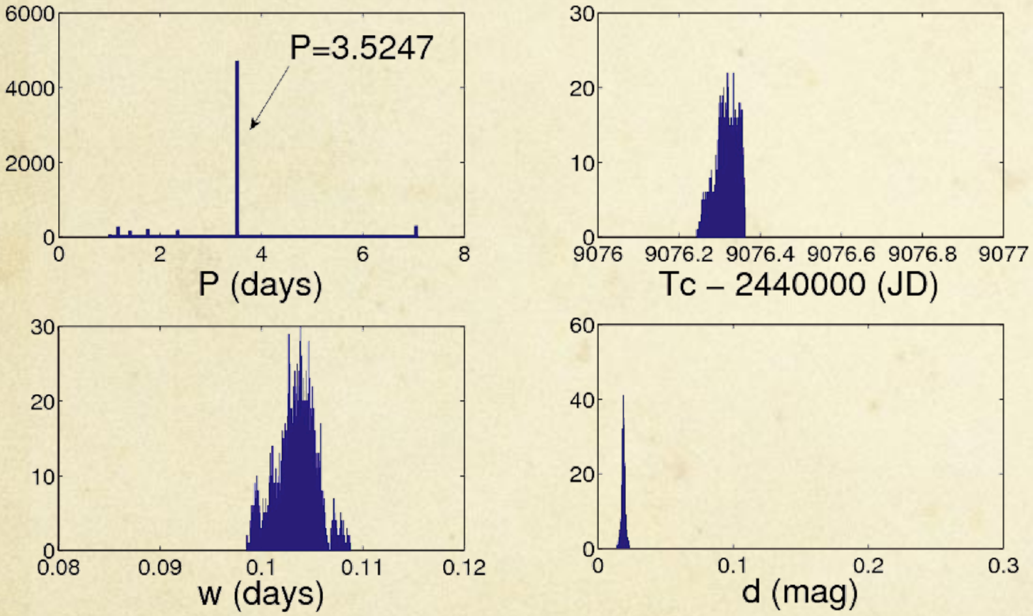
HD 209458: Follow-Up predictions Instantaneous Transit Probability –ITP(t)



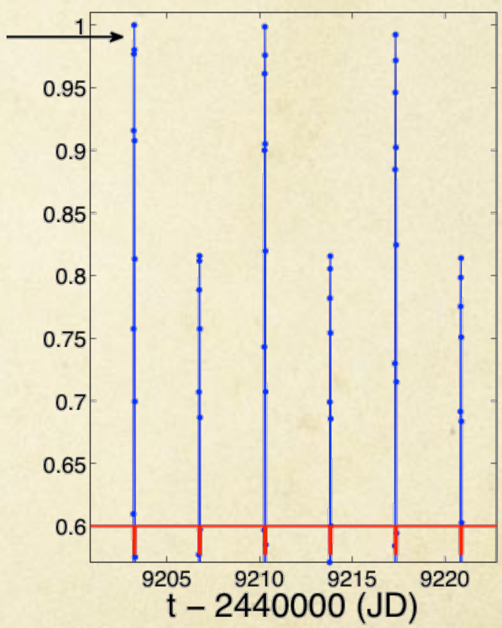
Dzigan & Zucker (2011)

HD 209458: *Hipparcos* combined with a Directed Follow-Up simulation

Posterior Distributions



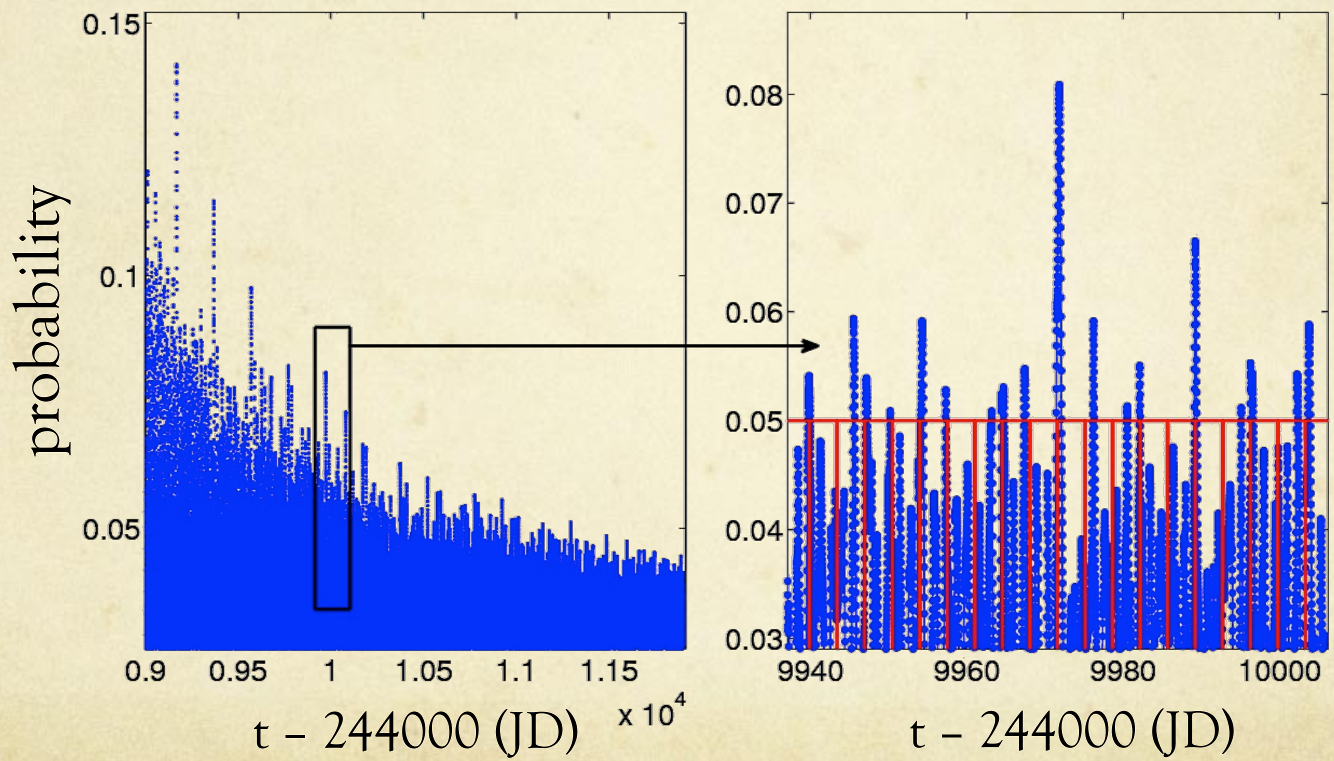
ITP (t)



Dzigan & Zucker (2011)

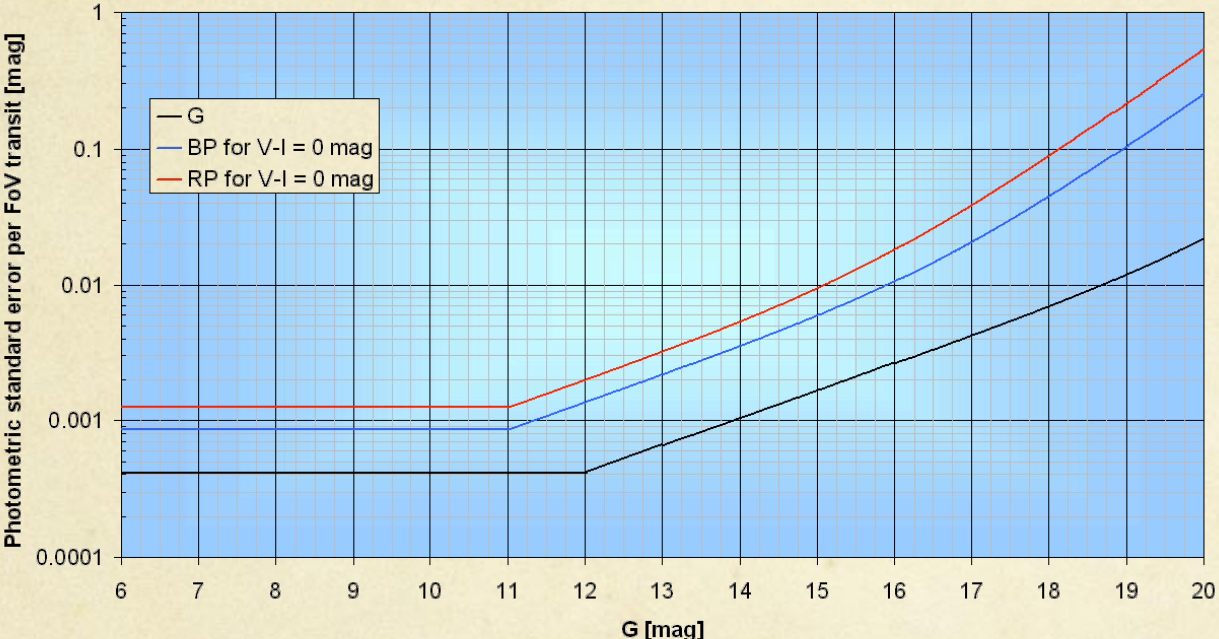
ITP degradation

ITP for 10 years after *Hipparcos* observed HD 209458



Dzigan & Zucker (2011)

Transiting Exoplanets by *Gaia* photometry



de Bruijne, J. H. J. (2012)

Photometry <2 *mmag* down to the 15th G - magnitude

Average of 70 samples per object

Optimized to derive parallaxes, proper motions, not for planetary transit search!

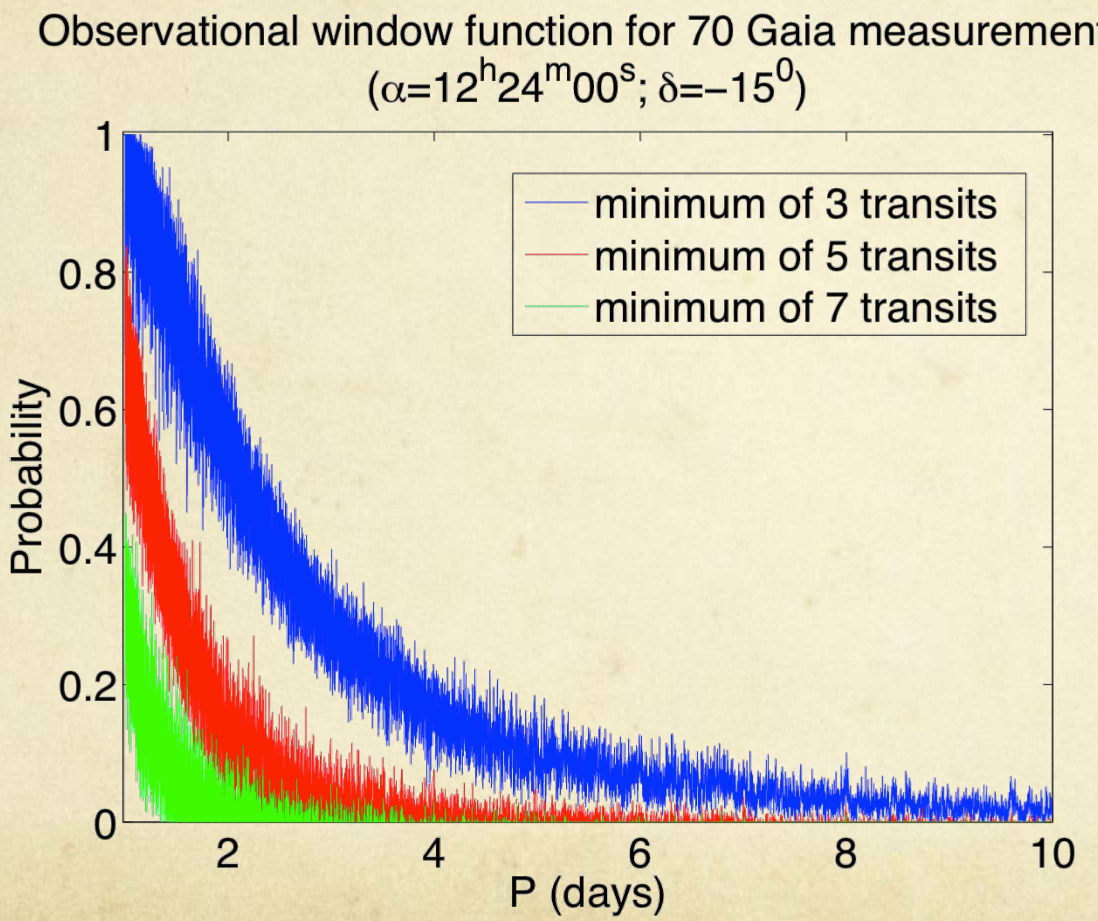
Is it worth it?
Gaia yield of transiting planets

$$\frac{d^6 N_{\rm det}}{dR_p dp dM dr dl db} = \rho_*(r,l,b) r^2 \cos b \frac{dn}{dM} \frac{d^2 f(R_p, p)}{dR_p dp} P_{\rm det}(M, r, R_p, p)$$

(*Beatty & Gaudi 2008)*

- Transiting HJs & VHJs frequencies from OGLE complete survey *(Gould et al. 2006)*
- Stellar density in the solar neighborhood *(Reid et al. 2002)*
- Galactic model *(Bahcall & Soneira 1980)*
- Transit detection probability as an Observational Window Function

Gaia Transit Observational Window Function



Assumptions:

Gaussian noise

No outliers

Minimum number of points in transit (3,5,7)

Dzigan & Zucker (2012)

Gaia expected yield

Assuming 2-hours transit…

- Down to 14^{th} G-magnitude:

  minimum 7 transits: ~70 transiting HJs and VHJs

  minimum 5 transits: ~200

  minimum 3 transits: ~600

- Down to 16^{th} G-magnitude:

  minimum 7 transits: ~300 transiting HJs and VHJs

  minimum 5 transits: ~900

  minimum 3 transits: ~2600

Directed Follow-Up strategy application for *Gaia*

CU-7 for Variability Processing

Laurent Eyer
University of Geneva
Department of Astronomy

- Simulated *Gaia* light curves inspired by known transiting planets (period, duration, coordinates)
- *Gaia* Scanning Law
- Phase chosen to produce required number of sampled transits
- Photon noise level – 1 mmag.
- We defined two main detection scenarios.

First scenario - *Gaia* data alone

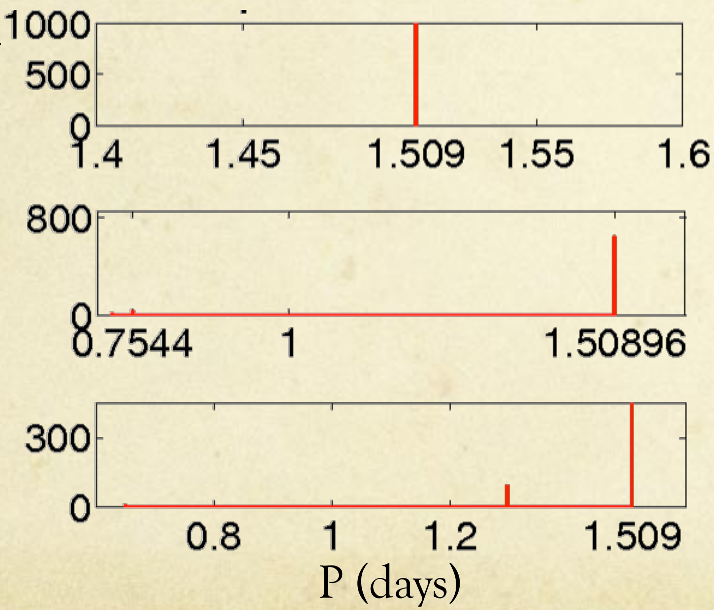
- Simulation inspired by CoRoT-1b (P=1.51 d, w=0.1 d)
- Assuming five sampled transits (N_{tot}=64)
- d > 0.005 mag

Period Posterior distribution

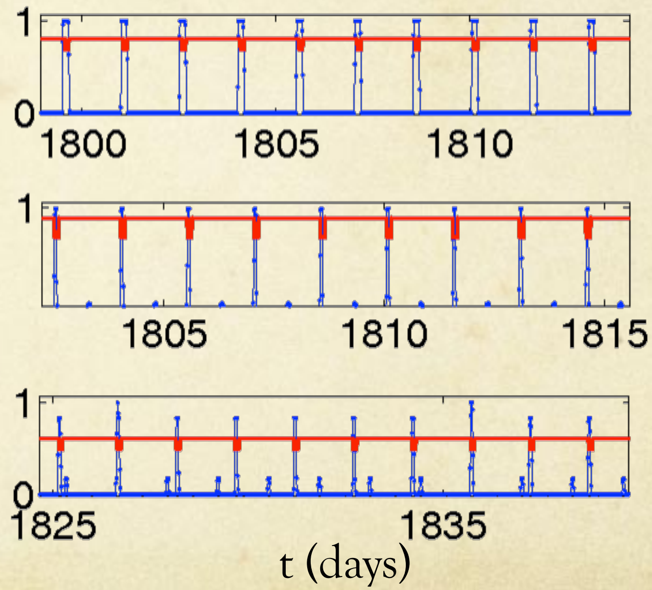
d=10 *mmag*

d=8 *mmag*

d=5 *mmag*



ITP



Dzigan & Zucker (2013)

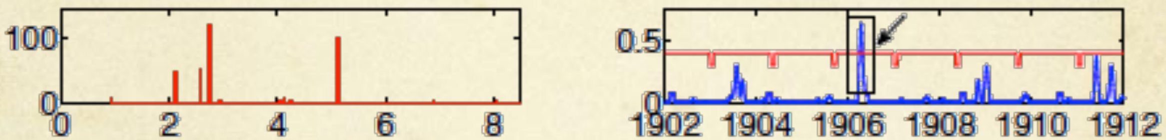
Second scenario – *DFU* observations

with **as little as 3** transit samples we will be able to **trigger** follow-up

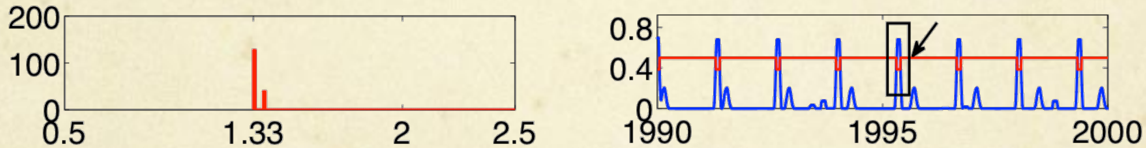
- Simulation inspired by WASP-4b (P=1.338 d, w=0.104 d)
- Assuming four sampled transits (N_{tot}=83)
- d = 0.005 mag

Gaia simulation

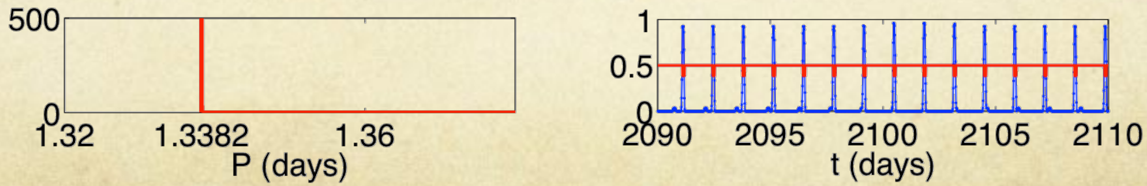
Period Posterior distribution **ITP**



Gaia combined with 1 *DFU* simulation



Gaia combined with 2 *DFU* simulations



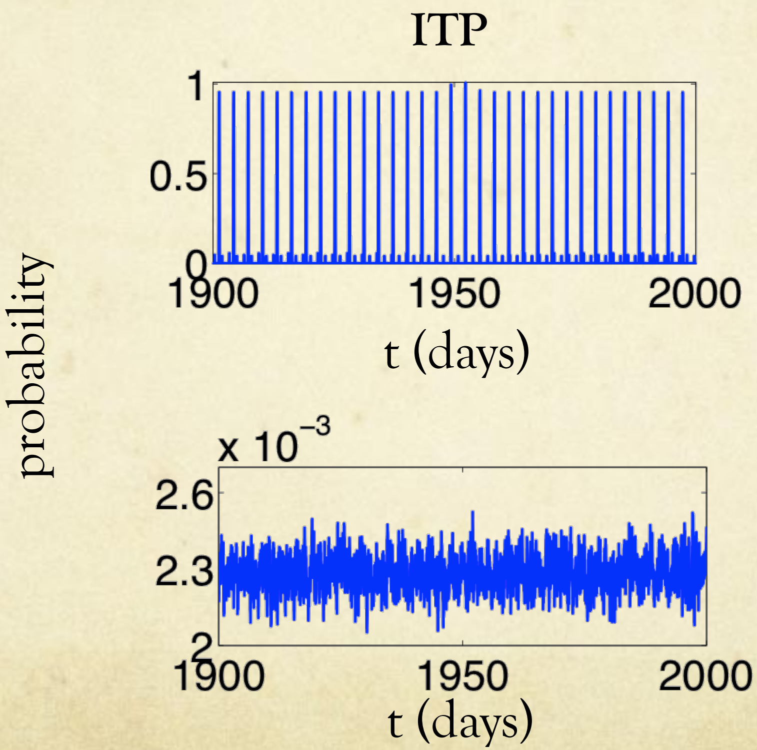
Dzigan & Zucker (2013)

Prioritizing candidates for Directed Follow-Up observations

1. ITP peak values > 0.1
2. Skewness of the ITP >1
3. Wald statistic of the transit depth

Transit simulation

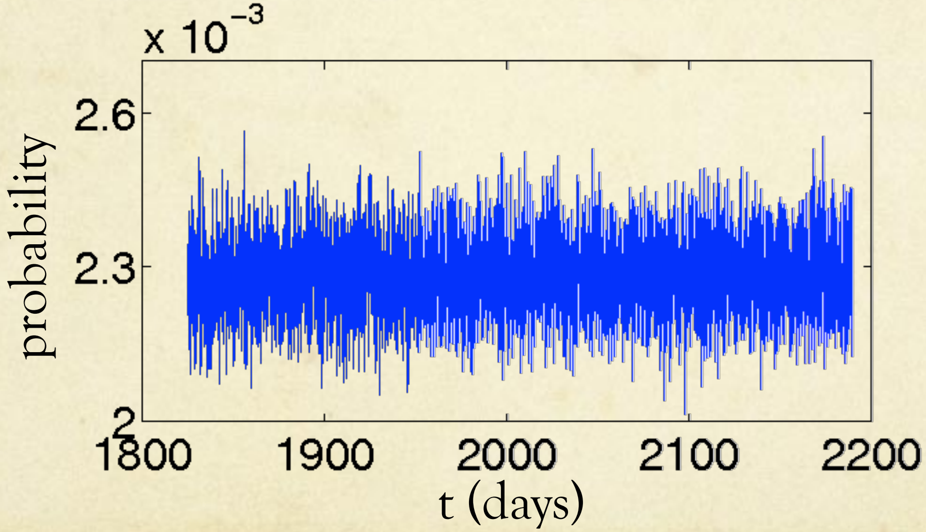
No Transit



False alarm treatment

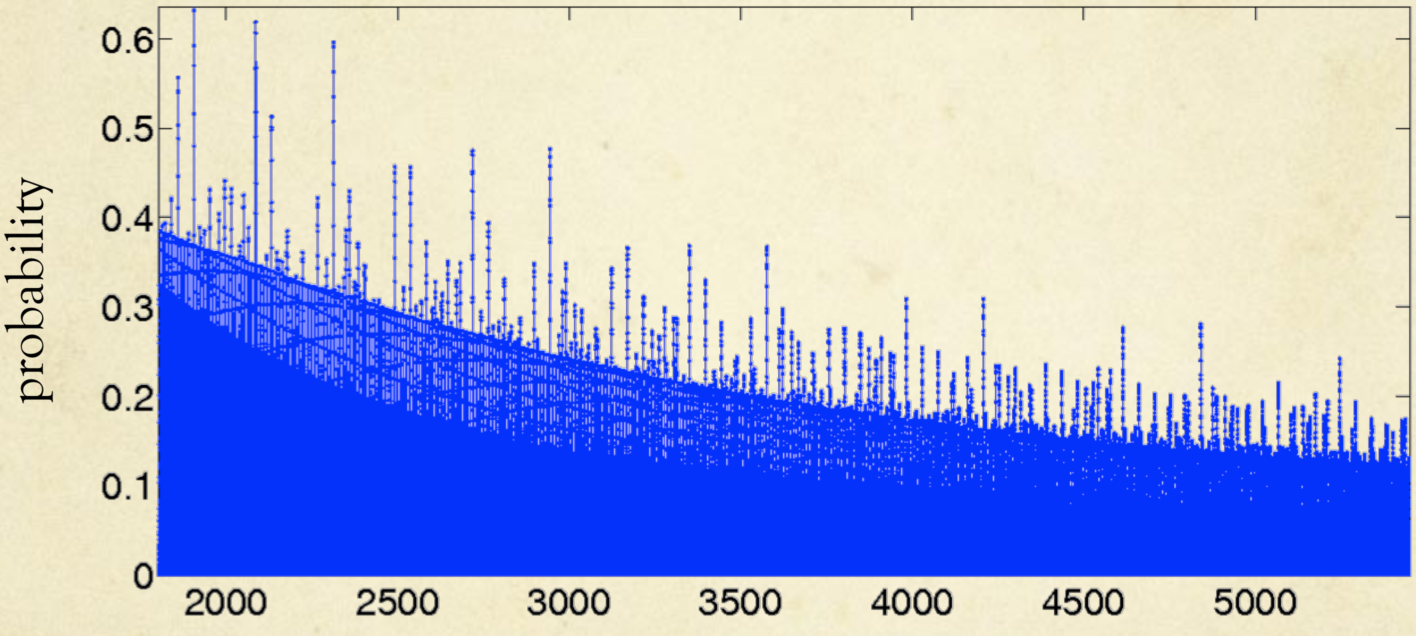
- Statistical false-alarm rate is negligible
- Red noise will manifest as effectively white noise

ITP for simulation with no transit (σ=3 mmag)



Initiating the Follow-Up campaign

ITP degradation

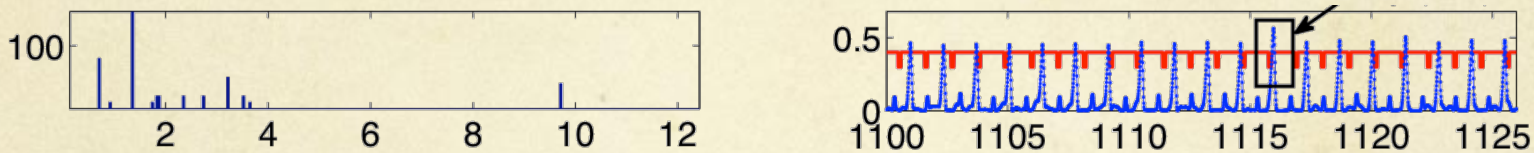


As soon as possible...
(while *Gaia* still operates)

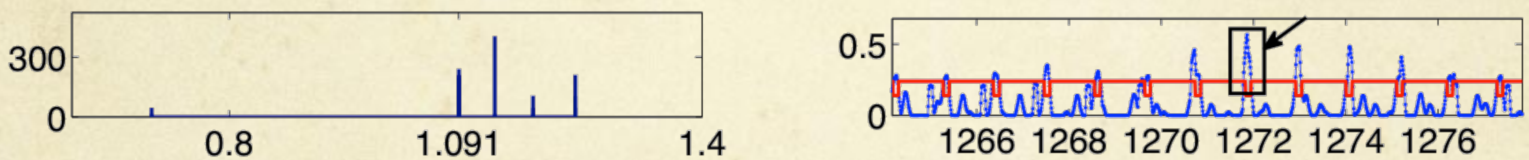
Directed Follow-Up for *Gaia*
Partial light-curve

WASP-12b: 3 transit samples @ half lifetime, d=7 mmag

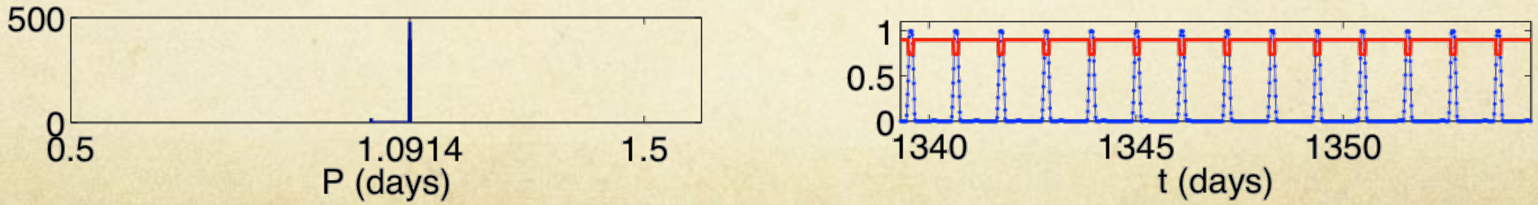
Gaia halftime simulation



Gaia halftime + 1 *DFU* simulation



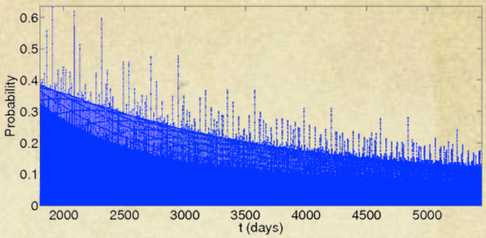
Gaia halftime + 2 *DFU* simulations



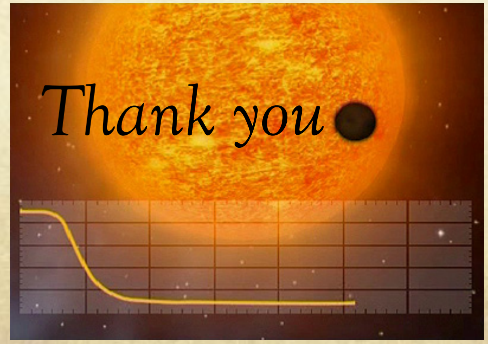
Follow-Up network for *Gaia* discoveries

- Widespread
- Moderate precision

Summary & Future



- Transiting Hot Jupiters are valuable (favorable for observational study)
- The Directed Follow-Up strategy utilizes low-cadence surveys for transit search
- Gaia yield can reach thousands of transiting planets
- More applications in many astrophysical phenomena (Eclipsing Binaries...) and surveys (OGLE, LSST...)



Dzigan & Zucker, 2011, MNRAS
Dzigan & Zucker, 2012, ApJL
Dzigan & Zucker, 2013, MNRAS