Scientific and engineering capabilities of the Gaia UB team applicable to the PLATO2.0 mission

J.M. Carrasco, F. Julbe, C. Jordi, J. Portell , E. Masana & X. Luri

Quantum Physics & Astrophysics department, University of Barcelona, Barcelona, Spain

Abstract

Our team at the University of Barcelona (UB) has been participating in the Gaia Mission since its very early phases. Among the different tasks developed for Gaia, UB team has contributed to the Data Simulations, Initial Data Treatment, Data compression, Photometric instrument design and calibration, Catalogue releases, among others. All this expertise should now be applied to PLATO 2.0 mission to allow its optimal results. In particular, our involvement in Gaia data releases can be used to adapt our simulation tools to PLATO 2.0 requirements in order to simulate the different stellar fields proposed and also determine the background contribution of faint stars observed by Gaia but not detectable with PLATO 2.0. Photometric transformations from Gaia passbands to PLATO and also synthetic photometry derived from Gaia low resolution spectra will be put in place. All these tasks will be developed under PSPM WP-131-150 (PLATO-Gaia simulations).

The Gaia UB team

The **Gaia UB team** consists of about 25 scientists, engineers and students with a very wide variety of skills and qualifications. Under the leadership of Jordi Torra, Xavier Luri, Carme Jordi and Francesca Figueras a wide range of tasks and responsibilities within the Gaia Data Processing and Analysis Consortium (DPAC) is fulfilled in close collaboration with teams from all around Europe.

The main responsibilities of the Gaia UB team within the Gaia framework can be seen in the following lists of tasks within the Gaia DPAC Coordination Unit (CU) system:

- **CU1**: Development of the **TmTools** interface between the Simulators GASS and GIBIS and the data processing systems
- **CU2**: Main responsibility for the development of the data simulators **GASS** (**GAia System Simulator**, for simulation of big Gaia telemetry datasets) and **GOG** (**Gaia Object Simulator**, for simulation of final mission data products and catalogue, Luri et al., 2014, A&A)
- **CU3**: Organization and implementation of the entire data processing chain from receiving raw telemetry to the core astrometric solution with **IDT** (**Initial Data Treatment**) and **IDU (Intermediate Data Updating)**
- **CU5 Photometric Calibration**: Main responsibilities are the definition of the internal calibration model of photometry and spectrophotometry, the selection of internal reference sources and the participation in the on-ground observational campaigns for standard flux calibration.
- **CU9**; Our team has main tasks in several working packages of the CU9 **Catalogue Access**. We are contributing significantly in the validation of the data and in the educational and outreach activities or science enabling applications. The FP7 project **GENIUS** lead by us is also devoted to CU9 activities.

The **Data Processing Center of Barcelona (DPCB)** is responsible for testing critical data reduction algorithms prior delivery to ESAC and the execution of the GASS simulator. It provides the main platform for executing IDU operations.

Several team members are participating in DPAC/ESA working groups devoted to some special features of the Gaia mission. We contribute to the work of the **Payload Experts (PE)** group, the **Initial In-Orbit Commissioning (IIOC)** group, the Radiation Task Force (RTF) and the **Offset Instability Task Force (OUTF)**.

Members of the team are active in the high-level **Gaia Data Processing and Analysis Consortium Executive (DPACE)** and the **Gaia Science Team (GST)**.

You can follow our work and activities via several resources:

1.) Our website: **http://gaia.ub.edu**

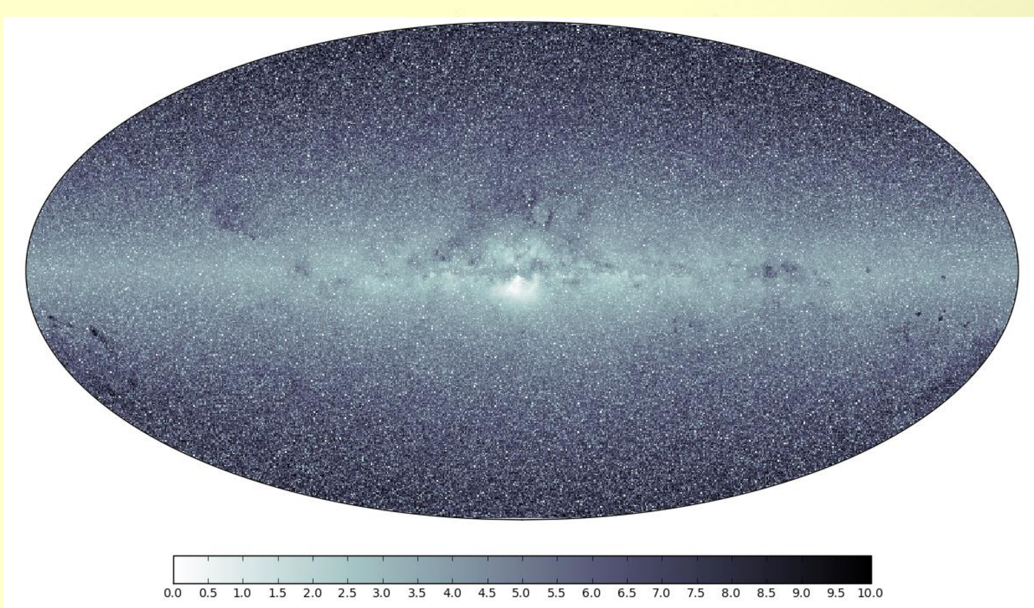
2.) Twitter: **https://twitter.com/GaiaUB**

3.) Facebook: **https://www.facebook.com/gaiaub**

Gaia Object Generator

During its five years of data collection, Gaia is expected to transmit to Earth some 150 terabytes of raw data, producing a catalogue of some 10^9 individual objects. After on-ground processing the full catalogue is expected to be in the range of one to two petabytes of data. Preparation for the exploitation of this huge amount of data is essential, and work is being undertaken to model the expected output of Gaia in order to predict the content of the Gaia catalogue and to facilitate the production of tools required to effectively analyze the data.

Therefore, DPAC has developed a set of simulators, including a simulator called the **Gaia Object Generator (GOG)**, which simulates the end of mission and the epoch transit catalogues, including observational errors. Simulation of many aspects of the Gaia mission were and are carried out by the CU2 Barcelona, in order to test and improve instrument design, data reduction algorithms and tools for the use of final Gaia catalogue data.



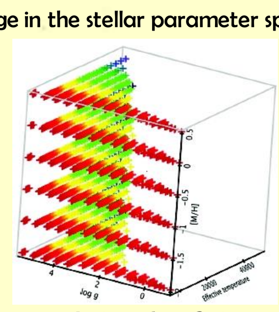
Skymap of total integrated flux over the Milky Way in the G band as simulated by GOG (Luri et al 2014). The colour bar represents a relative scale, from maximum flux in white to minimum flux in black.
The figure is plotted in galactic coordinates with the galactic longitude orientation swapped left to right.

One of the major deliveries of CU2 Barcelona is the **GOG end of mission catalogue**. This is a **full density single star population catalogue** down to Gaia G magnitude 20 using the Gaia Universe Model 2. Additionally to the detailed astrometric and 4 band photometric information it also contains the astrophysical parameters of the stars. The simulation was performed on the Mare Nostrum super computer at the **Barcelona Supercomputing Centre**, and it took 400 thousand CPU hours. **Similar simulations including binarity and planets will be executed for PLATO needs**. PLATO white light magnitudes could be added based on the colour-colour relationships. The content of future Gaia releases will update GOG error models and will we useful to evaluate faint Gaia sources to the background level.

Photometric relationships

Photometric relationships could be provided **for the PLATO white light magnitude** as it was done for Gaia magnitudes and other photometric systems in (Jordi et al, 2010, A&A) and also for the Kepler magnitude. The BaSeL-3.1 (Westera et al, 2002 A&A) synthetic SED library was used to derive these photometric relationships. The grid coverage in the stellar parameter space is the following:

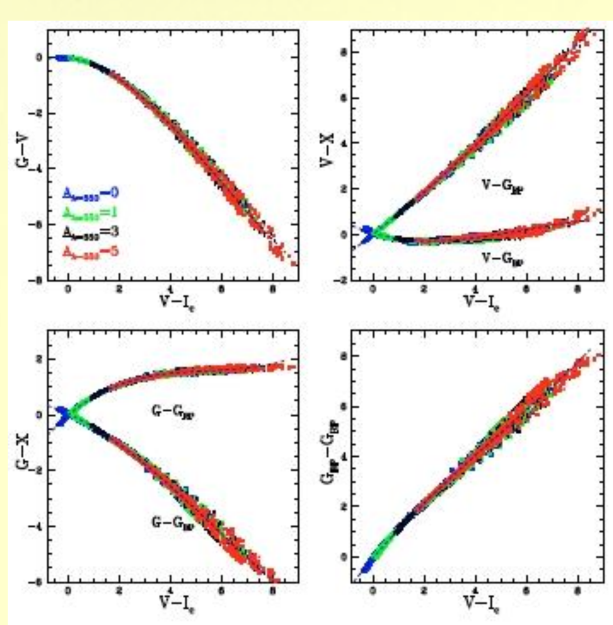
- $2000 < T_{eff} < 50000$ K
- $-1.0 < \log g < 5.5$ dex
- $-2.0 < [M/H] < +0.5$ dex
- $\xi_t = 2$ km·s^{-1}
- $9.1 < \lambda < 160\,000$ nm



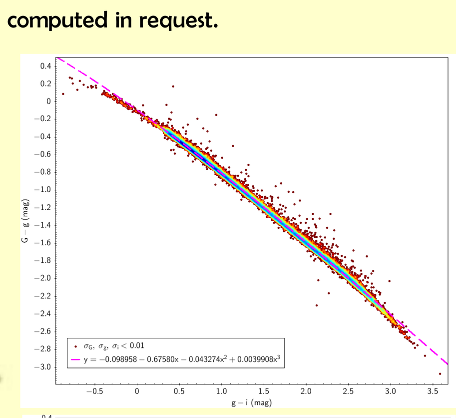
Basel-3.1 astrophysical parameters coverage (T_{eff}, logg and [M/H])

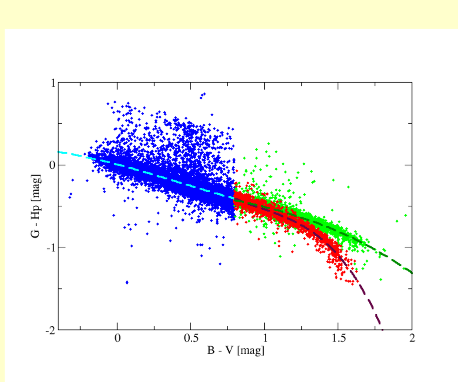
See the derived colour-colour diagrams which are relating the *Gaia* magnitudes to the **Johnson-Cousins** colours, in the figure to the right. Shown are the relations with V-I_C which is the one with the lowest residuals. The residuals are increasing in all cases for T_{eff} < 4500 K due to effects by surface gravity and metallicity.

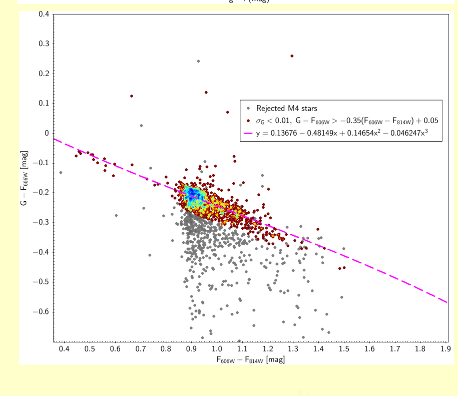
Relationships to any other photometric system (f.e. **Sloan Digital Sky Survey** photometric system (Fukugita et al. 1996, AJ, 111, 1748) used in several large surveys like UVEX, VPHAS, SSS, LSST) could be computed in request.

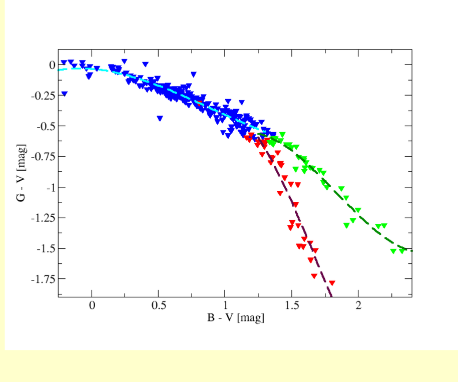


Colour-colour diagram involving all *Gaia* passbands and the V-I_C Johnson-Cousins passbands using BaSeL-3.1.









Photometric transformations derived from Gaia DR1 data to other photometric systems were already derived, see plots at the left (from top to bottom and from left to right SDSS, Hipparcos, Hubble and Johnson –Cousins magnitudes).

We crossmatched Gaia DR1 sources with those having available photometry in the external photometric systems to be considered. For Hipparcos and Tycho-2 relationships we used TGAS Gaia DR1 data. For deriving relationships with SDSS photometry sources in SDSS data stripe 82 were used. Johnson-Cousins transformations were derived using Landolt stars. Finally sources of the M4 cluster were used to derive photometric transformations from Gaia to Hubble photometry.

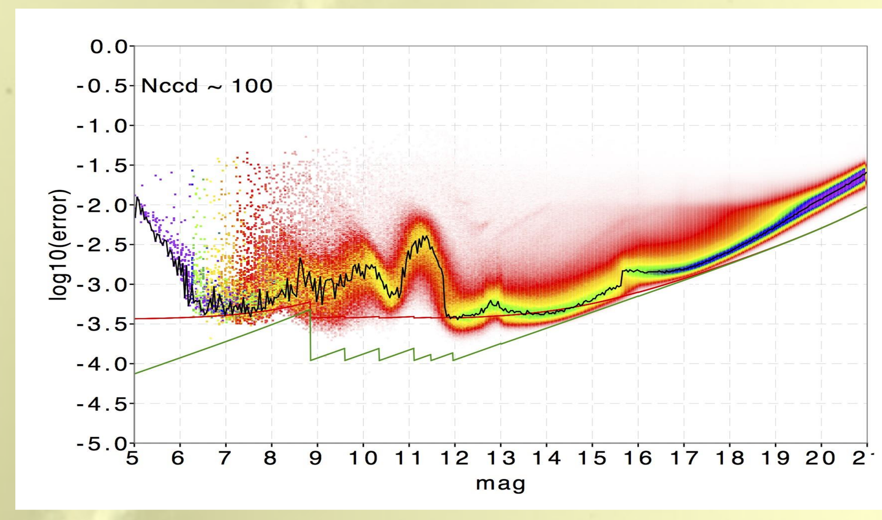
In order to obtain cleaner fittings, some filtering was done in each colour-colour diagram. The validity of these fittings is, of course, only applicable in the colour intervals used to do the fitting.

Gaia catalogue releases

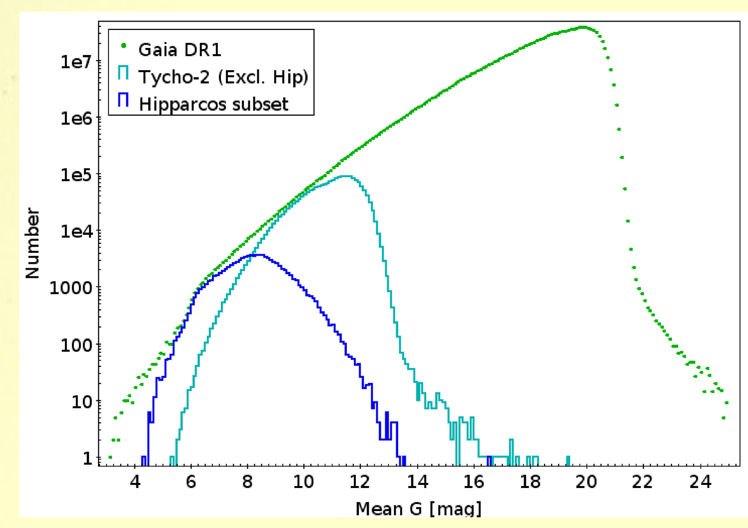
The data release scenario for the Gaia mission can be summarized as:

1. **14 Sep 2016:** α, δ, G magnitude for 1 billion single sources. Also parallaxes and proper motions for 2 million sources. 599 Cepheids and 2595 RR Lyr light curves.
2. **April 2018:** 5-parameter astrometric solution for at least 1 billion single stars, integrated BP/RP photometry + basic astrophysical parameters, mean radial velocities (G_{RVS}<12). Epoch astrometry for >10,000 asteroids
3. **2020:** Improved astrometry + photometry. Object classification and astrophysical parameters. BP/RP/RVS spectra for well behaved objects. Mean radial velocities and astrophysical parameters. Variable star classifications and epoch photometry. Solar system orbital solutions and epoch observations. Non-single star catalogue.
4. **Final release (2022):** Full astrometry, photometry and radial velocity. Variable star and non-single stars. Classification and astrophysical parameters. Unresolved binaries, galaxies and quasars. Exoplanet list. All epoch and transit data for all sources.

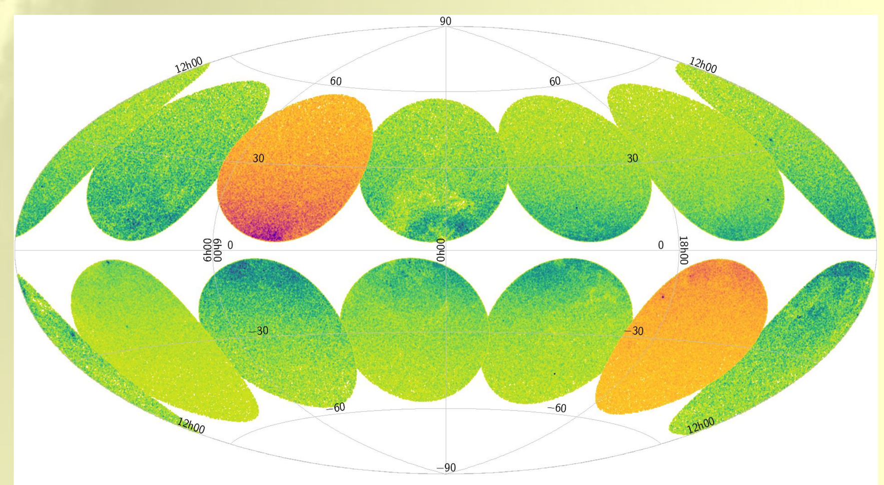
Our team have **relevant responsibilities in the Gaia DPAC CU9**, which is responsible for providing access to **all versions of the Gaia catalogue data** to the scientific community through the Gaia archive. CU9 will ensure the scientific correctness of the archive content by performing a thorough validation of the Gaia products before their publication. GOG has a direct impact in the Gaia real catalogue production, as the simulated Gaia data should be used for development, testing and validation of software. GOG datasets will be used to detect false-positives. An intentionally biased data set will be produced to validate that problems can been found. The **knowledge and understanding about the character and features of the photometric, spectrophotometric and spectroscopic data** of the ESA Gaia mission gained during its validation (and processing) should be applied during the PLATO2.0 target star selection process to allow optimal transit search results.



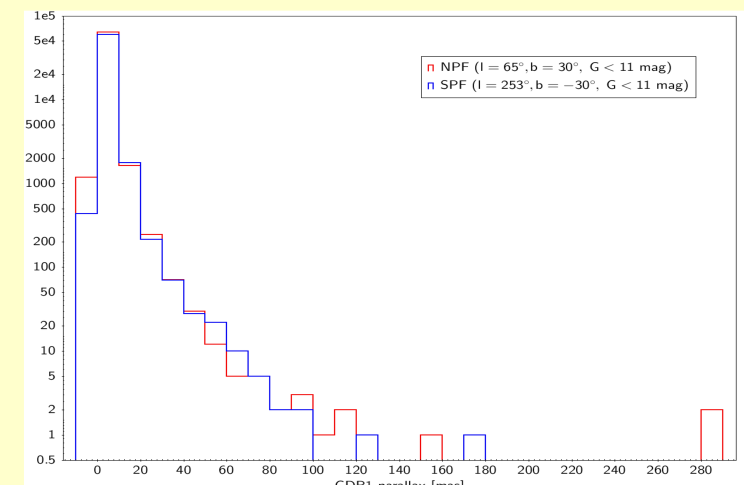
Gaia DR1 mean G error distribution as a function of magnitude. The black line shows the mode of the distribution. The green line shows the expected errors for sources with 100 CCD transits and for a nominal mission with perfect calibrations. The red line adds a calibration error of 3 mmag to the green line (*Evans et al., 2016*).



Gaia DR1 magnitude histogram. Most of the PLATO targets are already covered by the Tycho-Gaia Astrometric Solution (cyan line). Thus, potential PLATO targets have already available Gaia parallaxes and proper motions (see plot below).



PLATO fields proposed as seen by Gaia DR1 catalogue in galactic coordinates. Long duration fields (LOP) in the northern and southern hemispheres [NPF at (l,b)=(65º,30º) and SPF (l,b)=(253º,-30º) respectively] are marked in orange colours. The green fields are located at 60º galactic longitude difference from the LOP fields keeping the same galactic latitude. Every field was retrieved from GDR1 catalogue by using a search radius of 27º.



Gaia DR1 parallax histogram for targets in Northern and Southern PLATO fields (NPF and SPF respectively) with G<11 mag (covering then the P1 targets). Half of the sample are closer than 500 pc and 1% is closer than 70 pc (about 800 objects per field)

(l,b)	NPF= (65º,30º)	(125˚,30˚)	(185˚,30˚)	(245˚,30˚)	(305˚,30˚)	(125˚,30˚)
N_{GDR1}	75765	55027	59470	61631	70296	54489
(l,b)	SPF= (253º,-30º)	(313˚,-30˚)	(13˚,-30˚)	(73˚,-30˚)	(133˚,-30˚)	(193˚,-30˚)
N_{GDR1}	70534	79620	80209	72179	62903	52230

Number of sources published in Gaia Data Release 1 (GDR1) in an area of radius=27º around the central galactic coordinate shown in the table for every field.

PLATO-Gaia simulations (WP 131 150)

PSPM WP 131 150 goal is to implement additional elements to GOG to be adapted to PLATO mission:

- Derive (and update) photometric transformations from Gaia to PLATO photometry using Gaia catalogues. Predict PLATO magnitudes for Gaia sources.
- Update error models in GOG based on the latest Gaia catalogue
- Evaluate contribution of faint Gaia sources to PLATO background level.
- Adapt GOG to be used as simulation tool for other PLATO WPs.
- Provide simulations.
- Compile additional data that may need simulations for PLATO development and field definition.

Exoplanetary transits as seen by Gaia

Gaia photometry will allow to detect exoplanetary candidates with the transit method. The relatively low phase coverage due to the low number of FoV transit measured (70 transits x 4 min average) during the five year mission will not allow to detect all transiting planets.

A **study** was performed **to evaluate the number of expected transit candidates discovered by Gaia**. As a first step the stellar sample was derived with the GASS simulator tool downscaling the Milky Way model to 1/10th. This sample contains about 10 million stellar sources up to G magnitude 17. The G magnitude was computed from the V magnitude and the V-I colour by using the corresponding photometric relationships from Jordi et al (2010).

The planet sample is based on the statistics from the NASA Kepler transit search mission (Batalha et al. 2012, AAS). It was assumed that the Kepler sample of transiting planets is complete in detected planet sizes and orbital periods. This is well justified as the photometric precision of Gaia is less capable than the one of Kepler.

The planets were randomly distributed to a subsample (based on Kepler detection statistics) of 2.6 million stars. Further assumptions of the simulations are:

- Zero epochs for the transits were chosen randomly.
- Epochs of Gaia observations were chosen based on the Gaia scanning low with a typical number of 70 observations per star.
- Lightcurves were simulated to contain typical values of photon noise, background noise and RON. 20 percent of calibration noise was added.
- A transit was considered as detected with more than two independent signals

Results:

1.) Gaia will be able to detect up to 19000 transiting exoplanets all over the sky

2.) Signals down to 2 mmag depth are detectable.

3.) Planets with short orbital periods of only a few days are preferred for detection.

4.) Most transiting planets detected are Jupiter- or Neptune-sized.

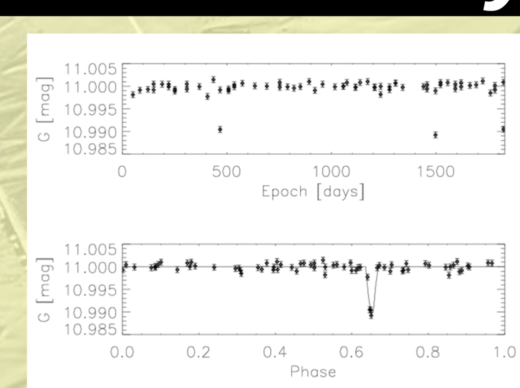
5.) A very few Super-Earths could be detected on short period orbits around M dwarfs.

Therefore it seems realistic that *Gaia* will detect **up to 19000 transiting planet candidates, many of them in the PLATO target fields.**

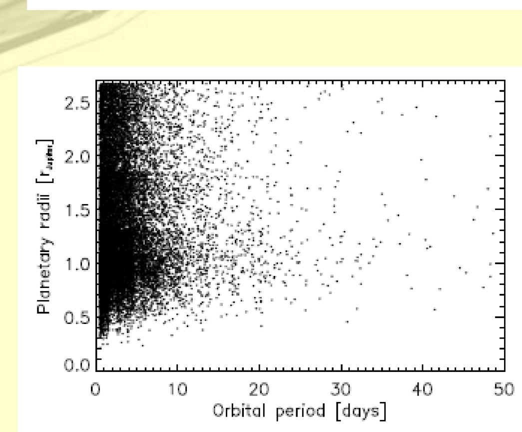
More details about this study can be found in. Voss et al. 2013 (SEA Proc.)

Similar studies for PLATO target fields can be conducted or supported.

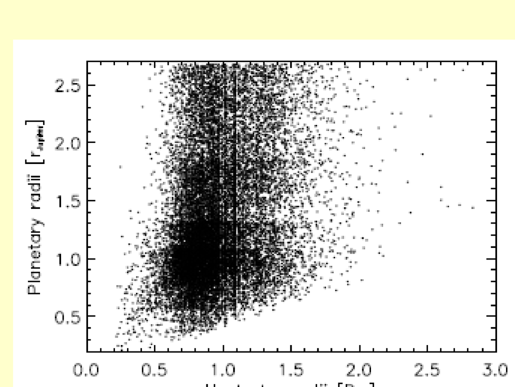
Stars with transiting planets detected by Gaia should be **preferred targets for PLATO2.0**.



Lightcurve of a star with a transiting planet showing four in-transit measurements. Note that one in-transit signal occurs during the ingress phase and is below the detection threshold.



Simulated planetary radii vs. orbital period of the detected 19000 transiting exoplanets



Planetary radii vs. host star radii for the 19000 host star – planet combinations as found in the simulations.

For more information please contact J.M. Carrasco (carrasco@fqa.ub.edu)