Exoplanet detection synergies between Gaia and the WFIRST Coronagraph

William Fanning[1], Neil Zimmerman[2], Michael McElwain[2,3], Gabriel Grell[4]

[1]Embry-Riddle Aeronautical University, [2]NASA Goddard, [3]NASA Roman Technology Fellow, [4]Harvard University

Abstract

WFIRST (Wide-Field Infrared Survey Telescope) is a NASA mission designed to study dark energy, exoplanets, and infrared astrophysics over a six-year period. One of WFIRST's instruments, the Coronagraph Instrument (CGI), will use advanced technology to image exoplanets and characterize their atmospheres in reflected starlight. We used a Monte Carlo approach to model the population of planets around nearby stars (distance < 20 pc), and then applied the detection limitations of Gaia and WFIRST CGI. The distribution model predicts that Gaia observations of bright, single stars will yield around 9 planets, 3 of which are accessible to WFIRST.

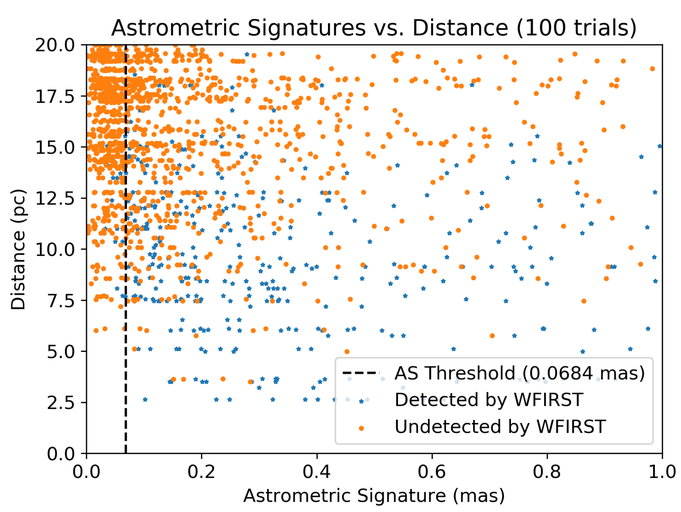
Gaia Exoplanet Discoveries for WFIRST

WFIRST's Coronagraph Instrument is capable of directly imaging exoplanets by suppressing the starlight of the planets' host stars. It can also characterize exoplanets through spectroscopy. There are already some targets that we know we want to look at; planets previously discovered by indirect detection methods such as the radial velocity technique. However, there may be observable exoplanets yet to be discovered. There are two ways of going about this: a blind survey of nearby stars with WFIRST, or discovering new nearby planets with other techniques. The recently launched Gaia astrometry mission may provide exoplanet discoveries observable by WFIRST. To assess the Gaia-discovered exoplanet yield we may expect, we created a planetary distribution model based from Cumming et al. 2008, which is derived from existing planet distribution frequencies.

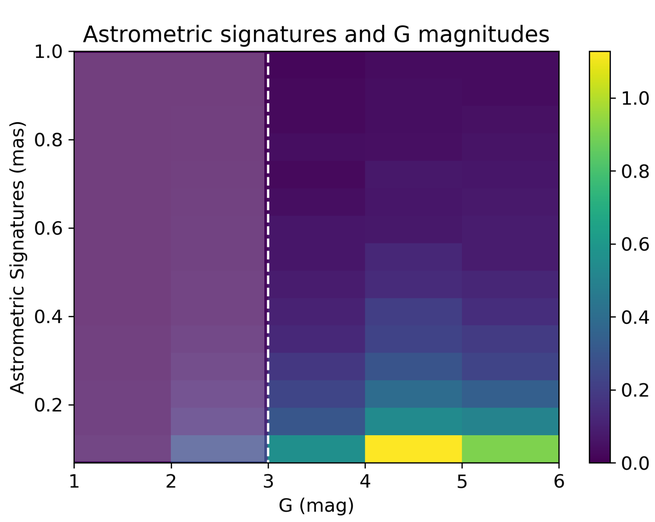
Simulating the Gaia Exoplanet Yield for Nearby Stars

The planetary distribution model was coded in Python 3. It starts by randomly generating a set of planet masses and periods between 0.3 and 10 Jupiter masses, and 2 and 2000 days respectively. It feeds these masses and periods into the power law fit, generating a distribution of planets. We expect 10.5% of nearby stars in this mass-period range to have planets, so planets are randomly assigned to known nearby stars (from the NExSci EXOCAT). The astrometric signatures and contrasts of these planet-star systems are calculated, and limitations from Gaia and WFIRST are applied to constrain the data. Finally, the results are displayed as a series of plots, based on distance, astrometric signature, G magnitude, and planet-star contrast. This process can be repeated many times if the user chooses, each trial representing a different "universe", so to speak.

To understand exactly what we can expect nearby planets to be like, different plots were created based on a number of different trials.



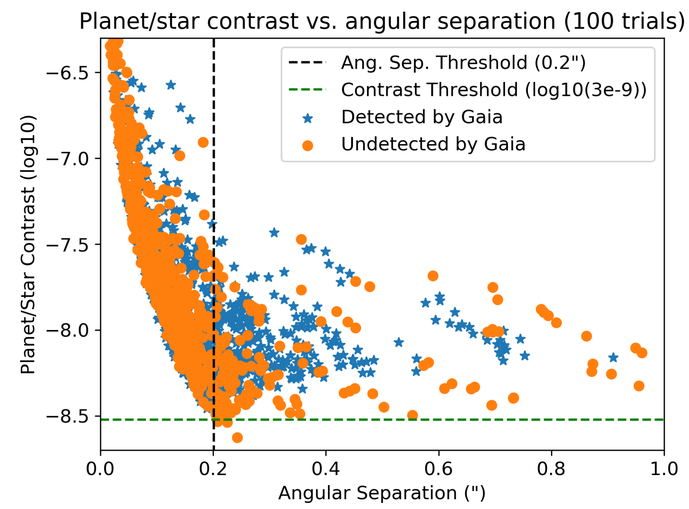
Above: Distance as a function of exoplanet astrometric signature, generated from 100 different random trials of the planetary distribution model. WFIRST has an inner working angle of 0.201 arcseconds at wavelength 770 nm; any planet/star that has an on-sky projected angular separation of less than 0.201 arcseconds is not detectable by WFIRST. WFIRST limits are applied here to show what planets can be observed by both WFIRST and Gaia.

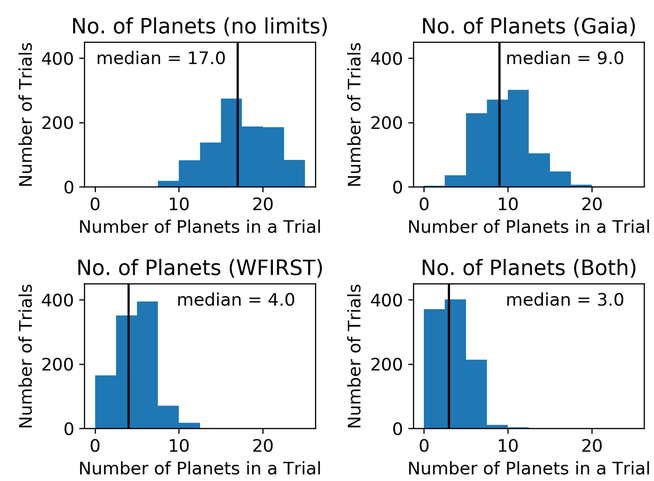


Left: 2D histogram of astrometric signatures and G magnitudes over 1000 trials. The white line denotes the G magnitude limit of Gaia. The colorbar on the right shows the planets per trial. Most planets have an astrometric signature from 0.0684 mas to 0.1 mas, and G magnitude from 4 to 5 mags.

Observability with the WFIRST CGI

Below: Planet-star contrast related to angular separation. Planet-star contrast is the ratio of star brightness to planet brightness. The lower the ratio, the brighter the star (in comparison to the planet). For example, the Sun-Earth contrast is 1e-10 at 600nm. Gaia has a detection limit of α > 0.0684 mas, and G > 3. Gaia limits are applied here to show what planets can be observed by both WFIRST and Gaia.





Left: four histograms, showing the total number of generated planets over 1000 trials. Top left has no limits, top right has Gaia limitations, bottom left has WFIRST limitations, bottom right has both. Median number of planets is displayed in a trial as well.

Common Name	HD	HIP	V	G	Spectral Type	Distance (pc)	Number of Planets
epsilon Eridani	22049	16537	3.71	3.47	K2.0V	3.21	0.099
omicron 2 Eridani	26965	19849	4.43	4.20	K0.5V	4.98	0.088
tau Ceti	10700	8102	3.49	3.28	G8.5V	3.65	0.086
epsilon Indi A	209100	108870	4.69	4.36	K4V	3.62	0.082
sigma Draconis	185144	96100	4.67	4.45	G9.0V	5.75	0.080
delta Pavonis	190248	99240	3.53	3.36	G8.0IV	6.11	0.077
___	115617	64924	4.74	4.56	G5V	8.56	0.075
___	10476	7981	5.24	5.01	K1V	7.53	0.071
___	191408	99461	5.32	5.06	K2.5V	6.01	0.068
82 Eridani	20794	15510	4.26	4.06	G8.0V	6.04	0.068

Above: top ten planets, ranked by the number of planets detectable by both WFIRST and Gaia. This table searches through results from all 1000 trials and locates what stars had a tendency to have planets over multiple trials. Values are: Common name (Bayer designation), HD number, HIP number, V magnitude, G magnitude, spectral type, distance, and number of planets per trial.

Conclusions & What's Next

The figures generated from the planetary distribution model reveals some information about the type and yield of exoplanets that may be discovered by Gaia and characterizable by WFIRST. The stars within 20 pc around which Gaia discovers exoplanets will most likely have a G magnitude between 4 and 5 mags and an astrometric signature between 70 and 100 μas. There are some stars that have a tendency to yield the most joint Gaia-WFIRST detections, for example Tau Ceti. If we model nearby exoplanetary systems with the Cumming et al. mass-period distribution, then we estimate that 3 planets detected by Gaia will also be observable with WFIRST CGI. Higher fidelity will be added to the the planetary distribution model, using a simulator of exoplanet imaging missions called EXOSIMS (github.com/dsavransky/EXOSIMS). EXOSIMS has its own planetary distribution function, and we want to combine the our simulation framework with EXOSIMS, and see if there is any appreciable difference in Gaia yield predictions between the model we have now and the EXOSIMS model.

References

M. Perryman, J. Hartman, G. A. Bakos, L., Lindegren. Astrometric exoplanet detection with Gaia, *Astro. Journal.* **797,** 14-36 (2014).

W. A. Traub, B. R. Oppenheimer, in *Exoplanets,* S. Seager, Ed. (Univ. Arizona Press, Tucson, 2010), pp. 111-154.

J. Chen, D. Kipping. Probabilistic forecasting of the masses and radii of other worlds, *Astro. Journal,* **837,** 17-30 (2017).

A. Cumming et al. The Keck planet search: detectability and the minimum mass and orbital period distribution of extrasolar planets, *PASP* **867**, pp. 531 (2008).

M. Turnbull. ExoCat-1: The nearby stellar systems catalog for exoplanet imaging missions, arXiv:1510.01731 (2015).