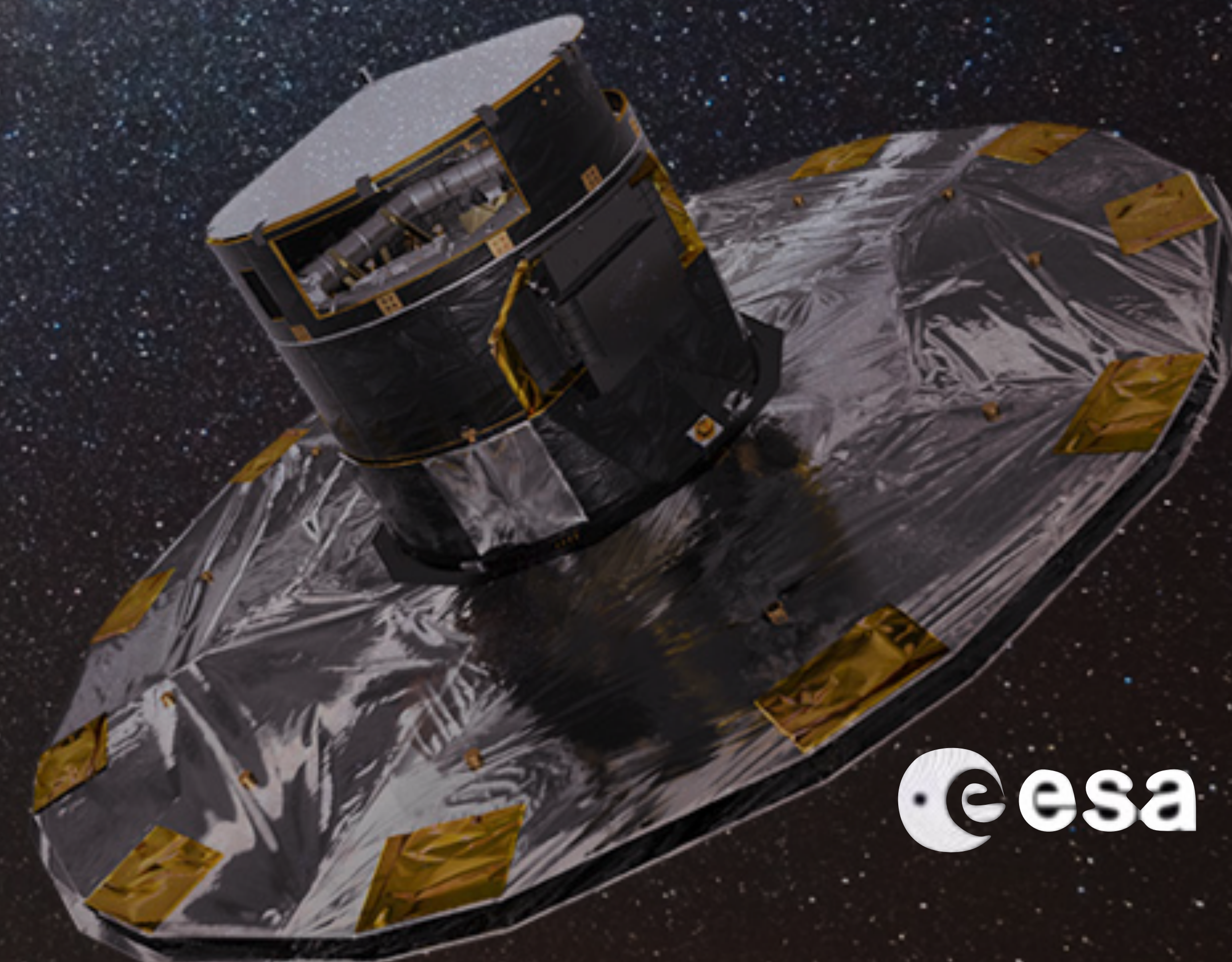
The Gaia Mission

A billion star map of the galaxy



Avi Shporer

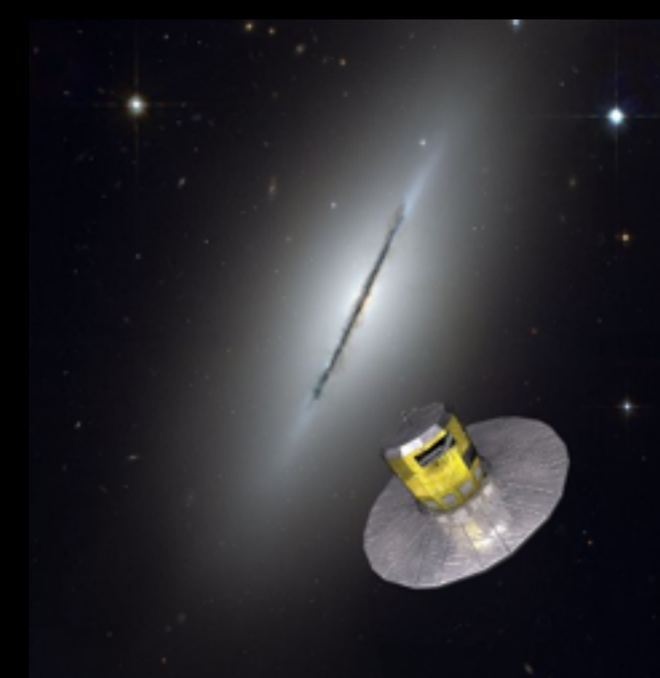
Sagan Fellow, JPL

SSW 2015, Pasadena

July 31, 2015

Take Home Message:

Gaia is a game changer in astrophysics and exoplanets



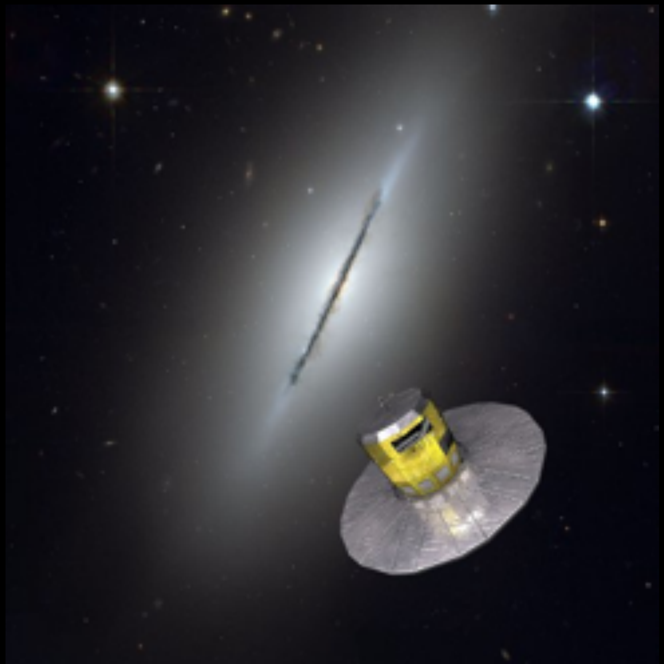
What is the Gaia Mission ?

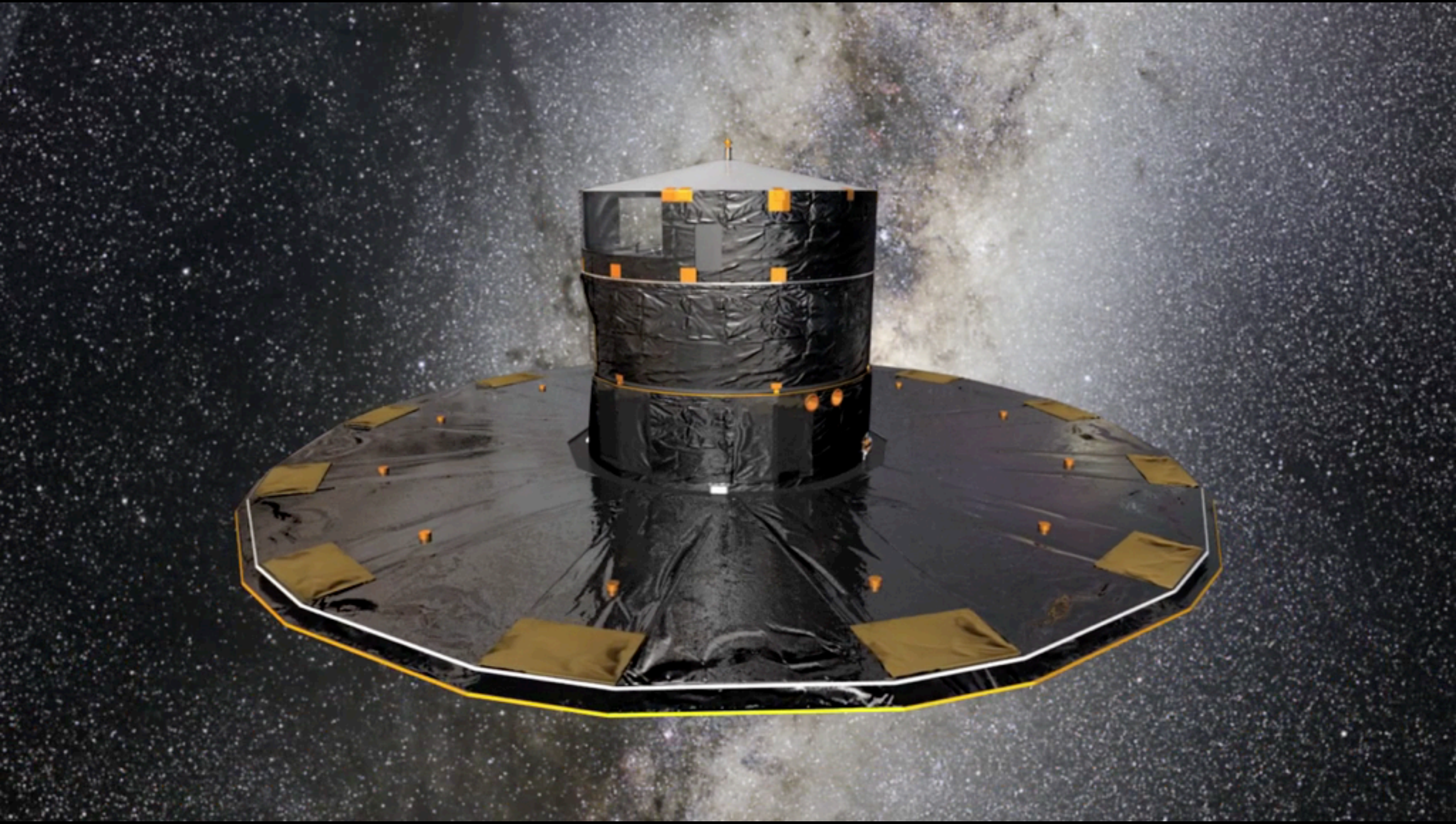
A Multidimensional 1 billion star survey:

3D position — Sky Position; Distance (parallax)

3D velocity — Proper motion; Doppler RV

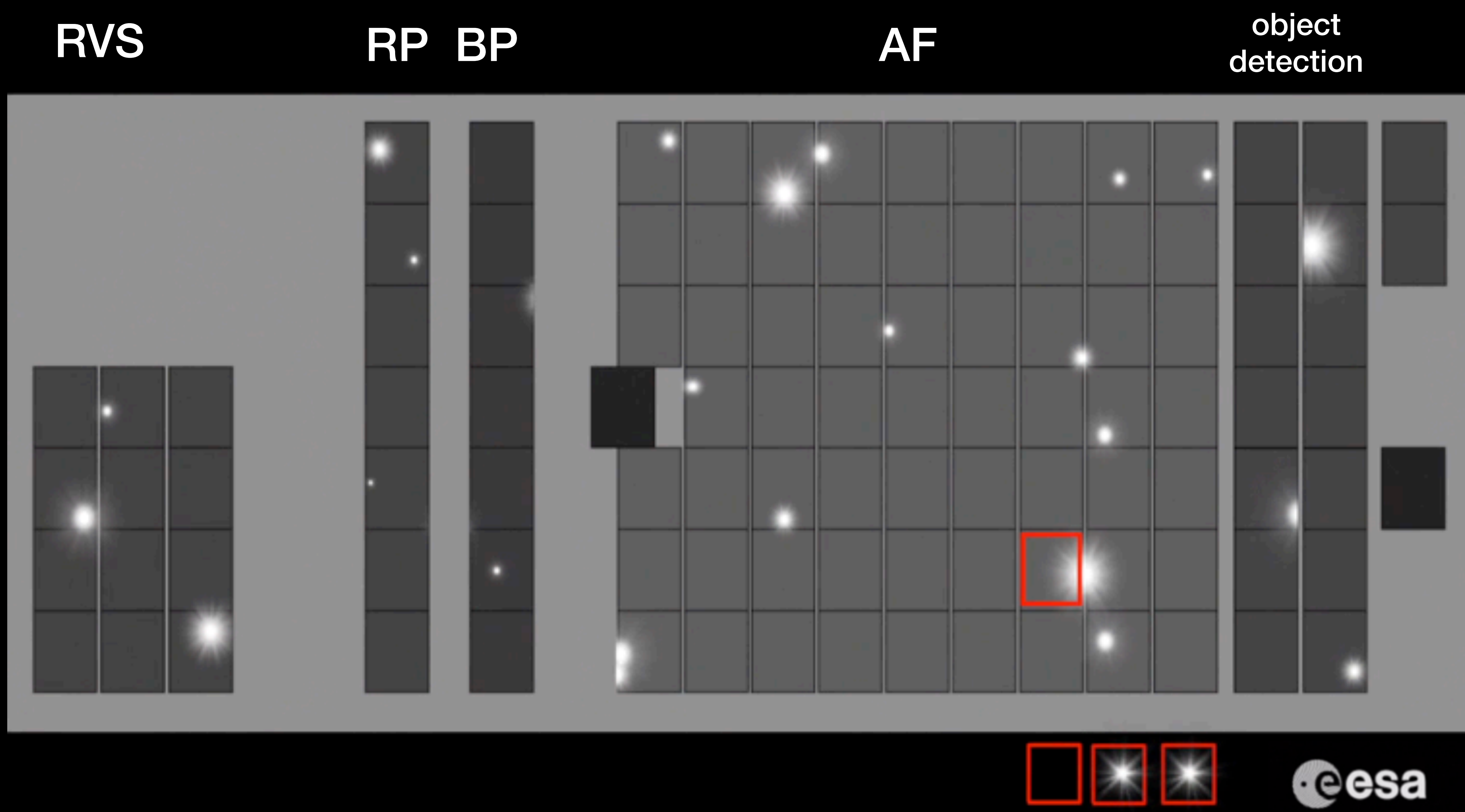
additional "dimensions" — Stellar characteristics:
- T_{eff}
- log(g)
- Metallicity





Gaia focal plane

- Astrometric Field (AF), 330-1050 nm, *G*~20 mag
- Spectro-photometry, 62 pix spectroscopy:
  - Blue Photometer (BP), 330-680 nm
  - Red Photometer (RP), 640-1050 nm
- Radial Velocity Spectrometer (RVS), *R*=11500, 847-871 nm, *V*~16 mag



Gaia Performance

Astrometry:

	B1V	G2V	M6V
$V-I_C$ [mag]	-0.22	0.75	3.85
Bright stars	5-14 µas (3 mag < V < 12 mag)	5-14 µas (3 mag < V < 12 mag)	5-14 µas (5 mag < V < 14 mag)
V = 15 mag	26 µas	24 µas	9 µas
V = 20 mag	600 µas	540 µas	130 µas

Photometry:

Noise level in milli-magnitude

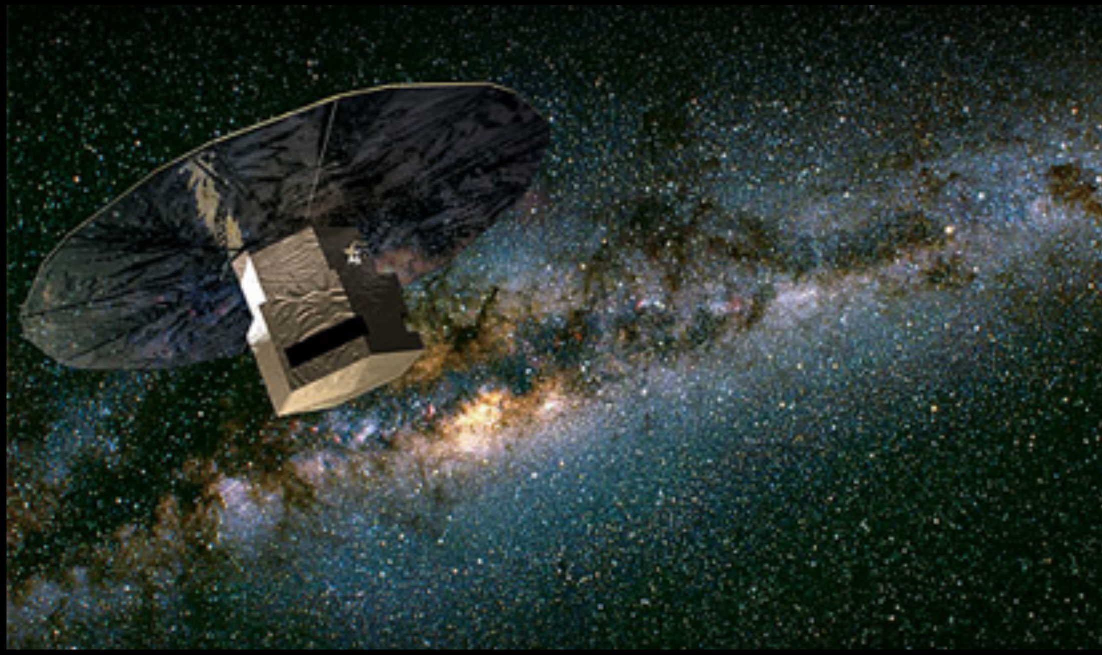
	B1V			G2V			M6V		
G [mag]	G	BP	RP	G	BP	RP	G	BP	RP
15	1	4	4	1	4	4	1	7	4
18	2	8	19	2	13	11	2	89	6
20	6	51	110	6	80	59	6	490	24

Radial velocity:

Spectral type	V [mag]	Radial-velocity error [$km\,s^{-1}$]
B1V	7.5	1
	11.3	15
G2V	12.3	1
	15.2	15
K1III-MP (metal-poor)	12.8	1
	15.7	15

Gaia Mission Trivia

- Launch: December 2013
- 50-110 epochs in 5 years (2014-2019)
- Possible extended mission: up to 5 years
- 2 x 0.7 m^2 rectangular mirrors
- L2 orbit
- Price: 940 M Euro (ESA + member states)
- 106 CCDs, ~1 billion pixels
- Diameter: 3.5 m (10 m with Sun shield)
- Weight: ~2.0 Tons
- FOV: 0.85 x 0.66 deg
- Gaia, not GAIA…



Science with Gaia

Galactic structure

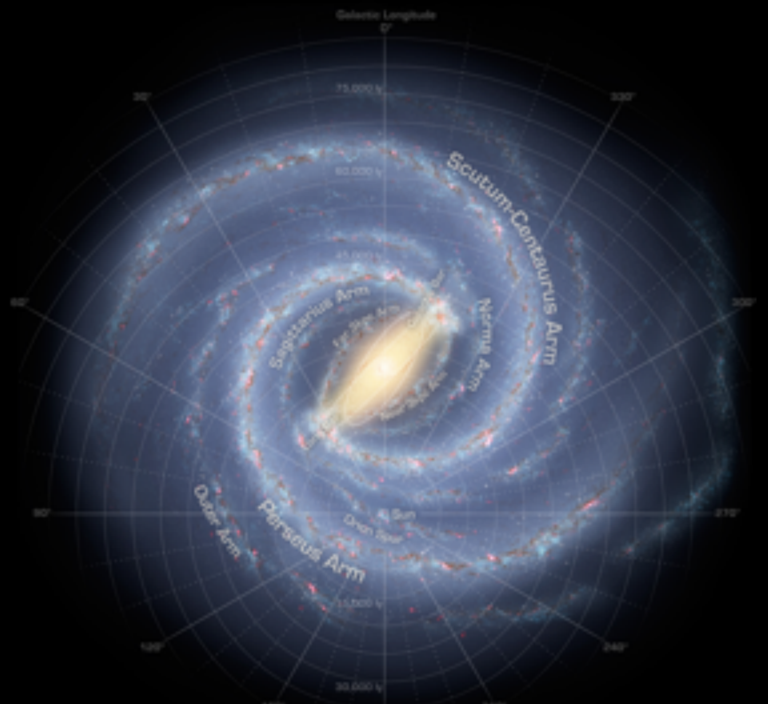


Image: X. Luri & DPAC-CU2

Stellar evolution

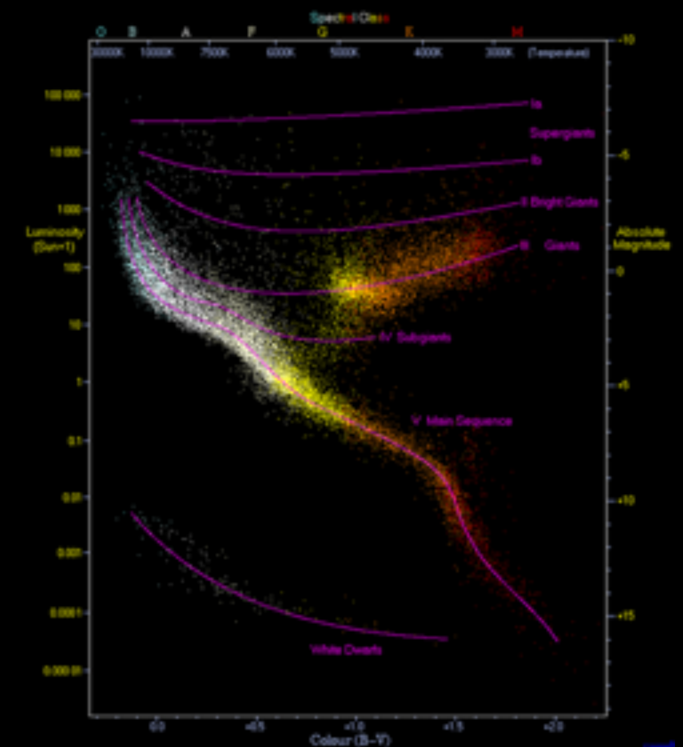
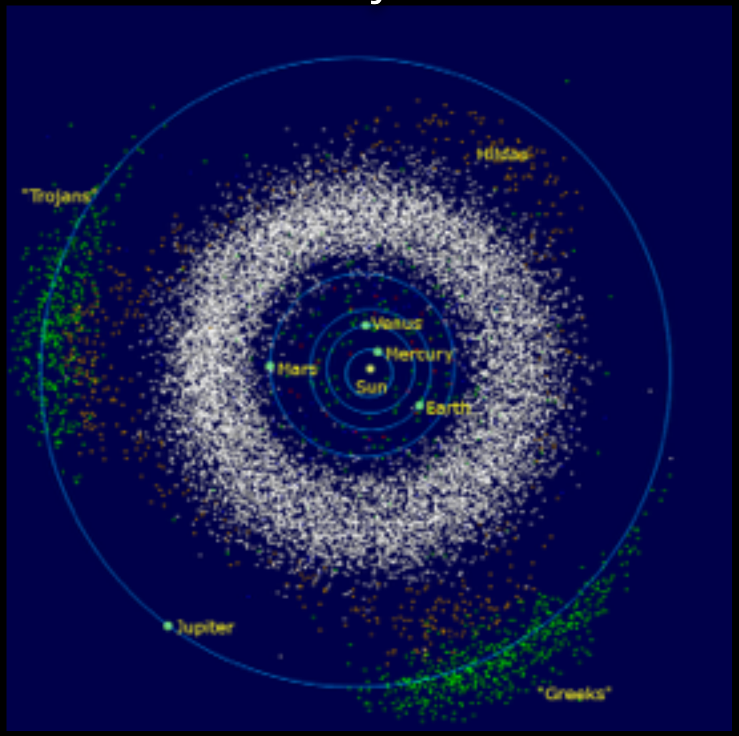


Image: Richard Powell

Solar system



Variable and binary stars

Image: ESO/L. Calçada

Exoplanets

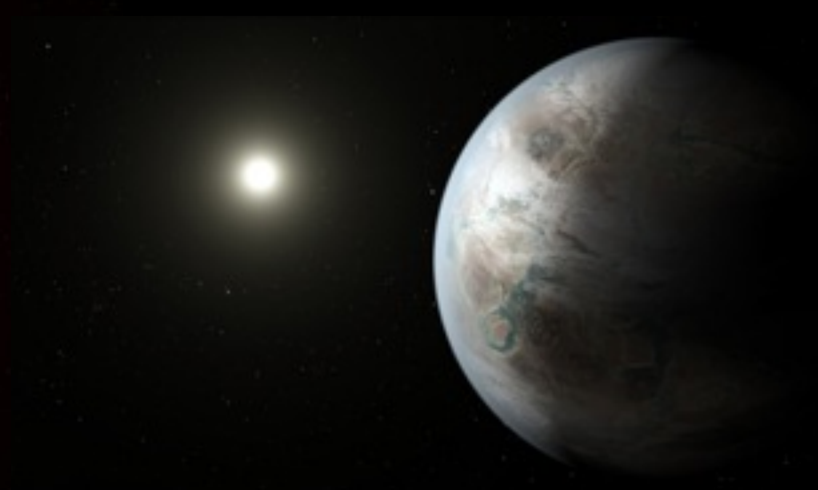


Image: NASA Ames/JPL-Caltech/T. Pyle

Supernovae

Image Credit: High-Z Supernova Search Team, HST, NASA

Exoplanets with Gaia

Exoplanets with Gaia

Astrometric signal:

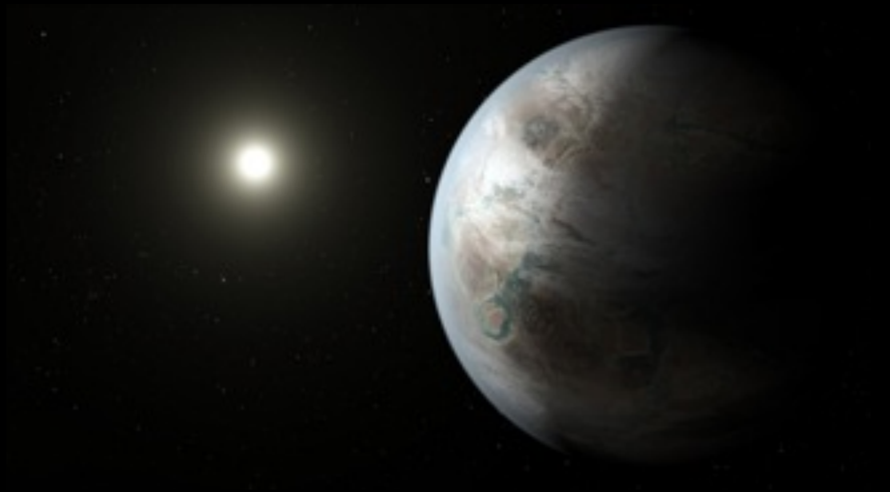
$$\alpha_s = \left(\frac{a_s}{\mathrm{AU}}\right)\left(\frac{d}{\mathrm{pc}}\right)^{-1} \mathrm{arcsec}$$

$$a_s M_s = a_2 M_2$$

$$\Longrightarrow \quad \alpha_s \approx \left(\frac{M_2}{\mathrm{M_J}}\right)\left(\frac{M_s}{\mathrm{M_\odot}}\right)^{-1}\left(\frac{a_2}{\mathrm{AU}}\right)\left(\frac{d}{\mathrm{pc}}\right)^{-1} 10^3\ \mu\mathrm{as}$$

For bright stars:

- single measurement $\sigma_{\mathrm{fov}} \approx 30$ µas,
- parallax $\sigma_\omega \approx 10$ µas



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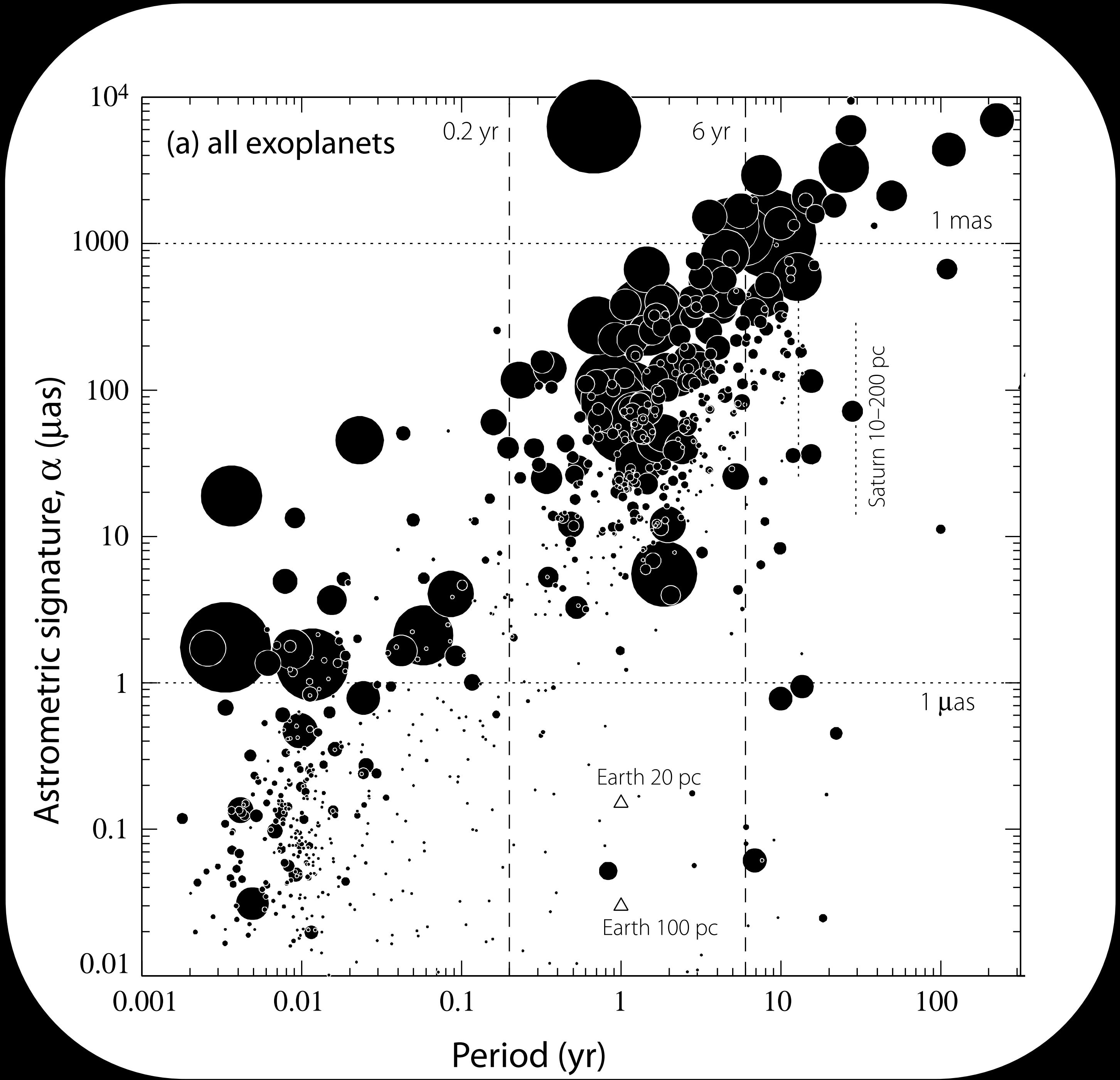
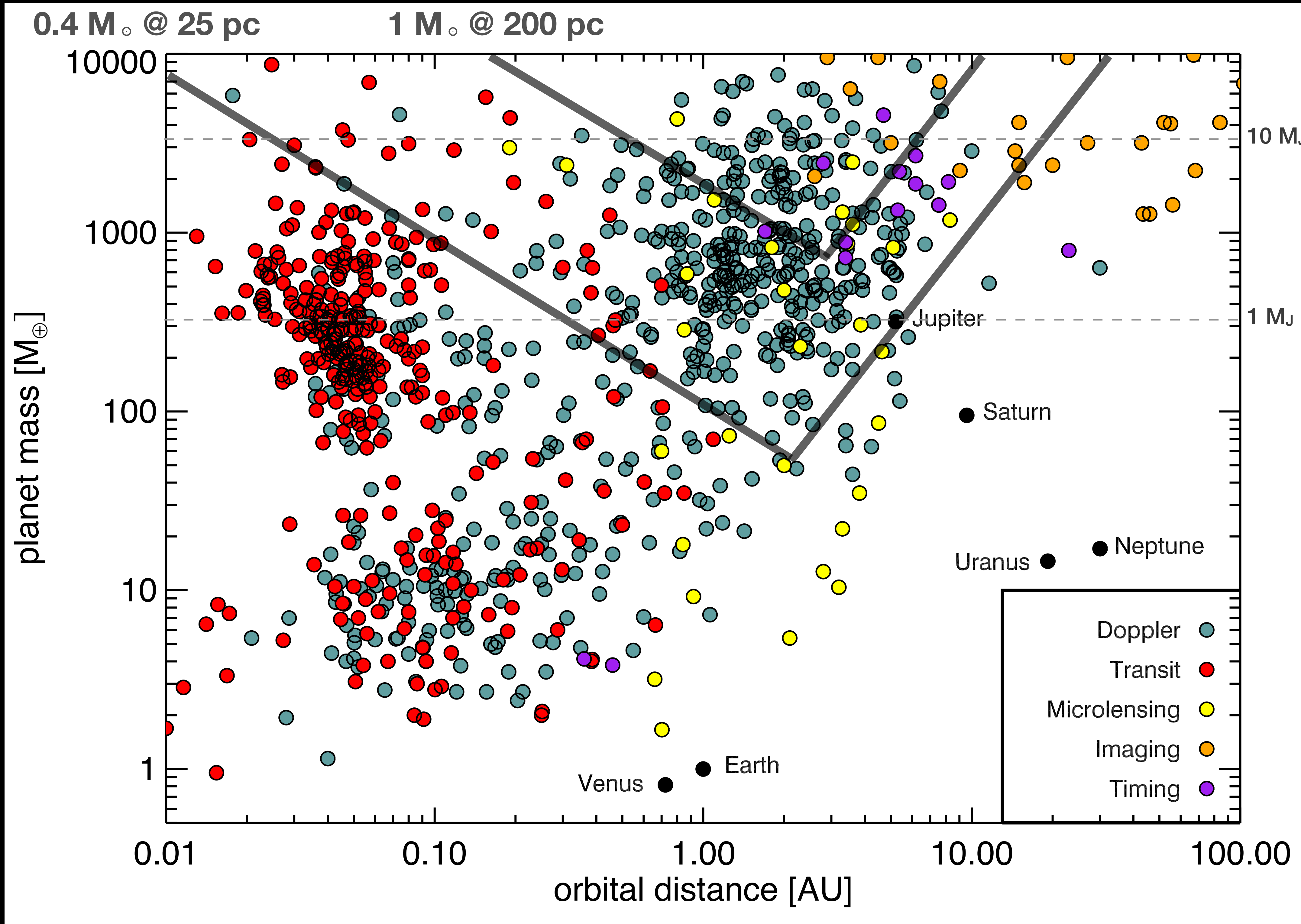


Unknown distances assumed to be 1,000 pc
Circle radius proportional to planet mass

Perryman et al. 2014

$$\alpha_s \approx \left(\frac{M_2}{\mathrm{M_J}}\right)\left(\frac{M_s}{\mathrm{M_\odot}}\right)^{-1}\left(\frac{a_2}{\mathrm{AU}}\right)\left(\frac{d}{\mathrm{pc}}\right)^{-1} 10^3\ \mu\mathrm{as}$$



Winn & Fabrycky 2015, Sozzetti 2011

"Astrometric exoplanet detection with Gaia"

Perryman, Hartman, Bakos, Lindegren 2014, ApJ, 797, 14

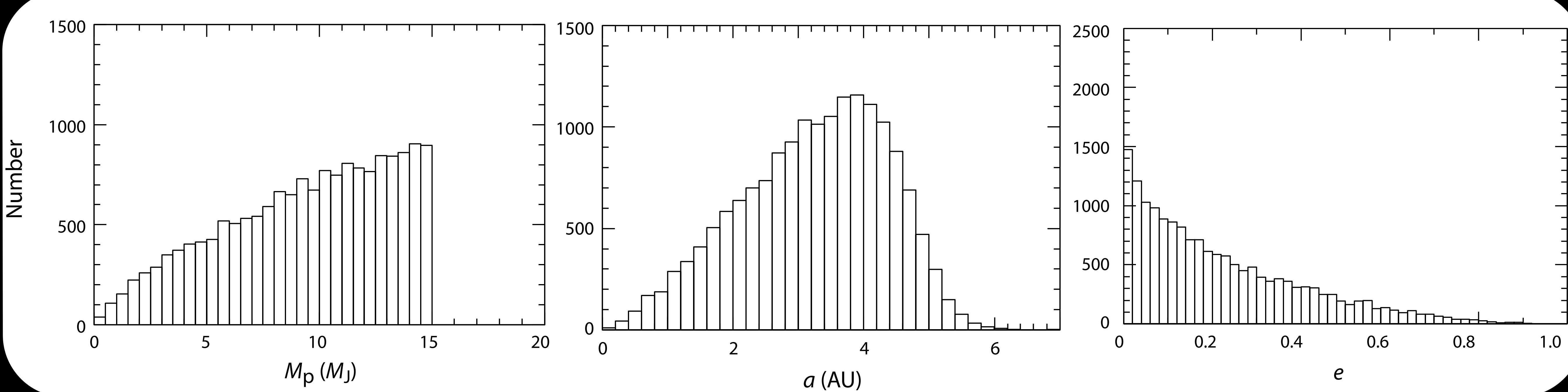
ABSTRACT

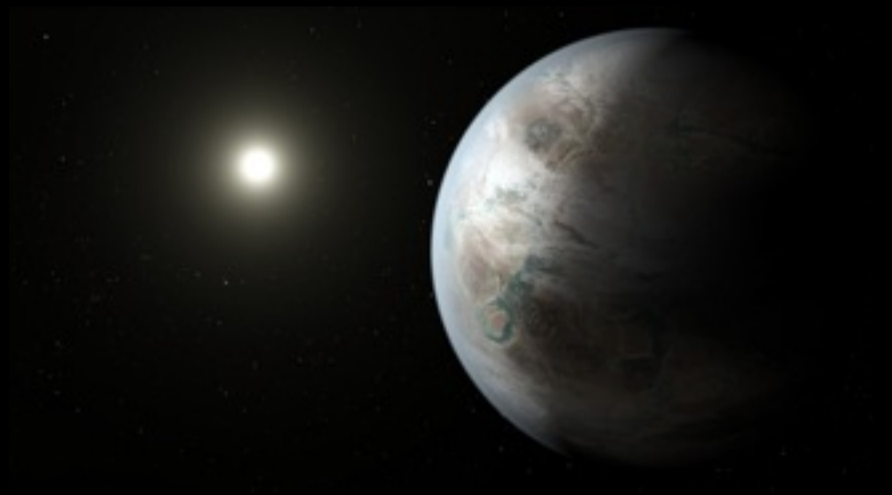
We provide a revised assessment of the number of exoplanets that should be discovered by *Gaia* astrometry, extending previous studies to a broader range of spectral types, distances, and magnitudes. Our assessment is based on a large representative sample of host stars from the TRILEGAL Galaxy population synthesis model, recent estimates of the exoplanet frequency distributions as a function of stellar type, and detailed simulation of the *Gaia* observations using the updated instrument performance and scanning law. We use two approaches to estimate detectable planetary systems: one based on the signal-to-noise ratio of the astrometric signature per field crossing, easily reproducible and allowing comparisons with previous estimates, and a new and more robust metric based on orbit fitting to the simulated satellite data. With some plausible assumptions on planet occurrences, we find that some 21,000 (±6000) high-mass ($\sim$1–15M_J) long-period planets should be discovered out to distances of $\sim$500 pc for the nominal 5 yr mission (including at least 1000–1500 around M dwarfs out to 100 pc), rising to some 70,000 (±20,000) for a 10 yr mission. We indicate some of the expected features of this exoplanet population, amongst them $\sim$25–50 intermediate-period ($P \sim$ 2–3 yr) transiting systems.

"Astrometric exoplanet detection with Gaia"

Perryman, Hartman, Bakos, Lindegren 2014, ApJ, 797, 14

Simulated detections:





“Astrometric exoplanet detection with Gaia”

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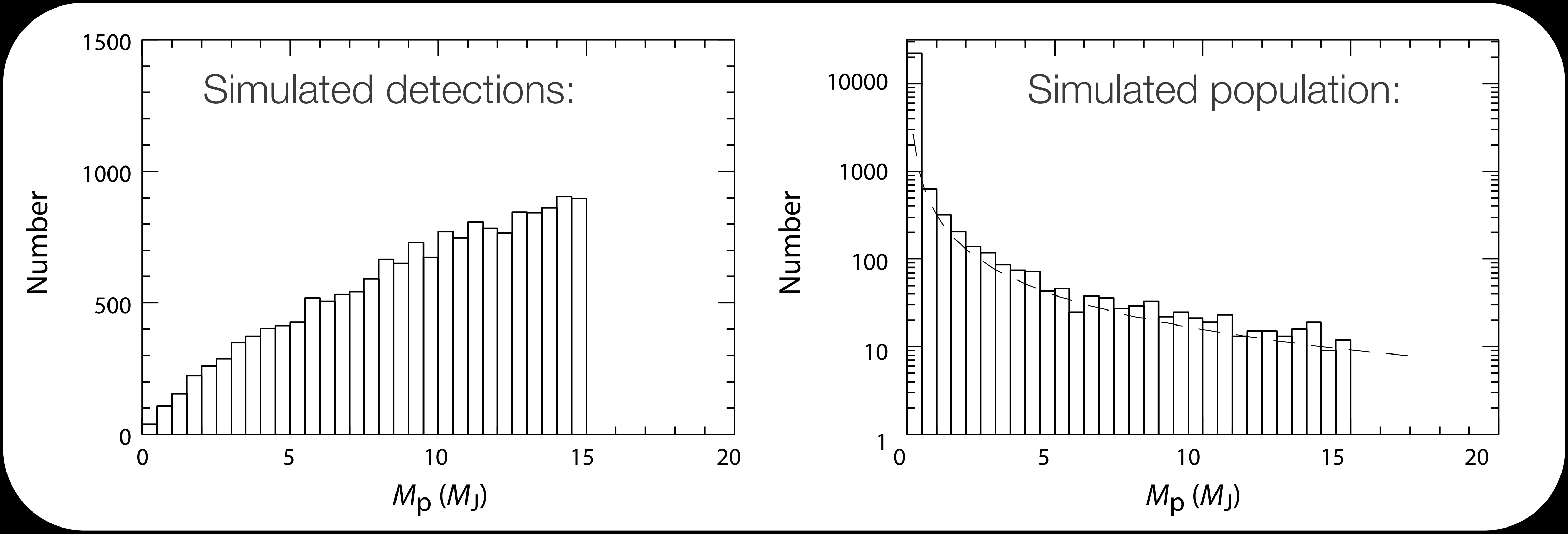
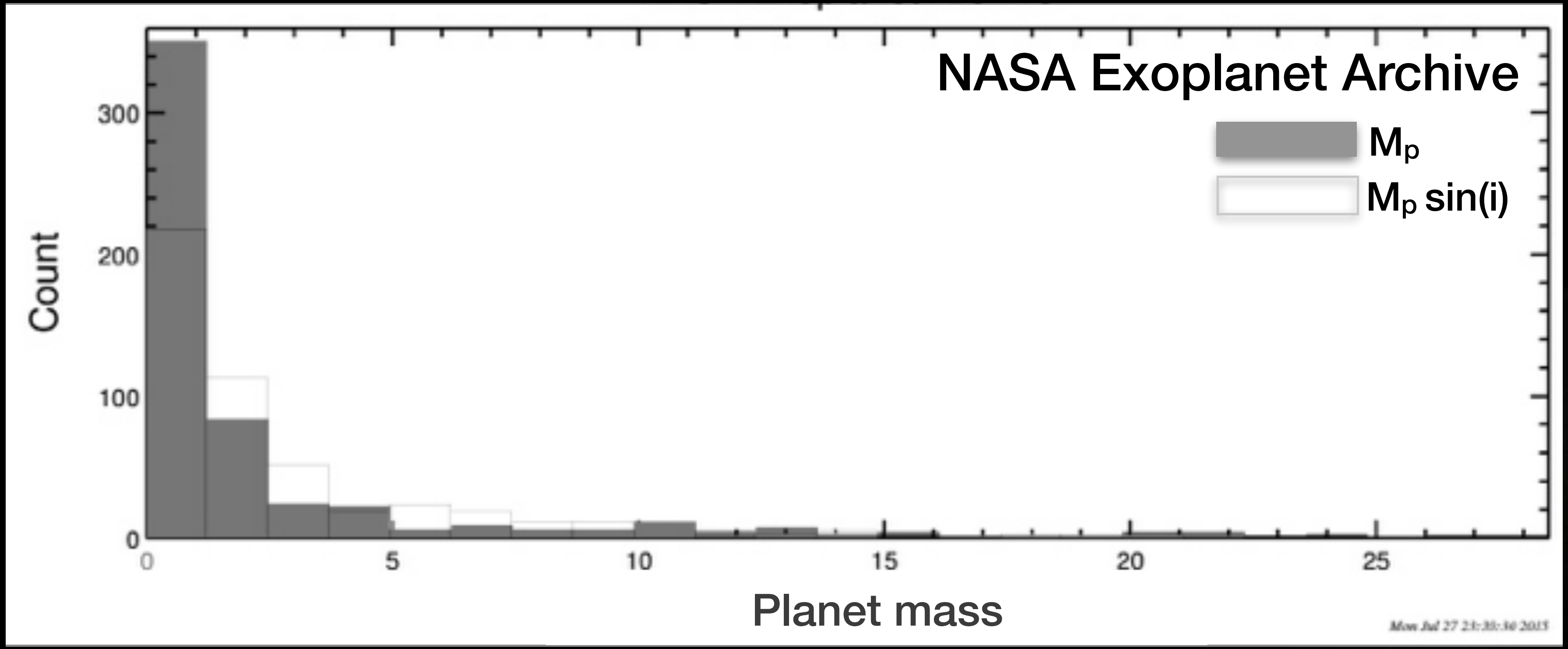
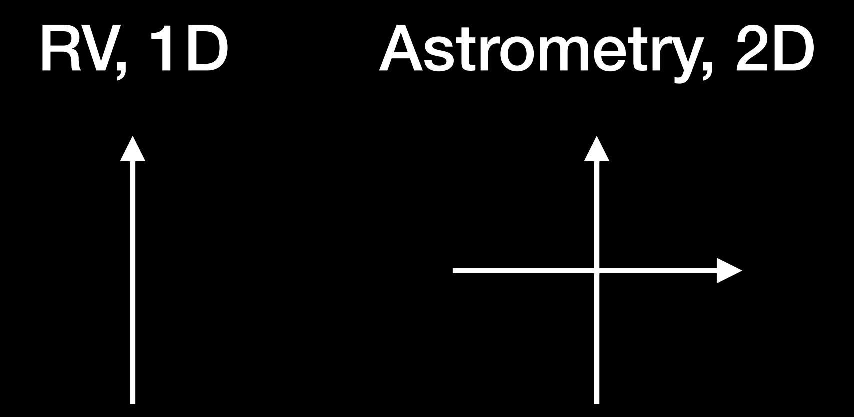




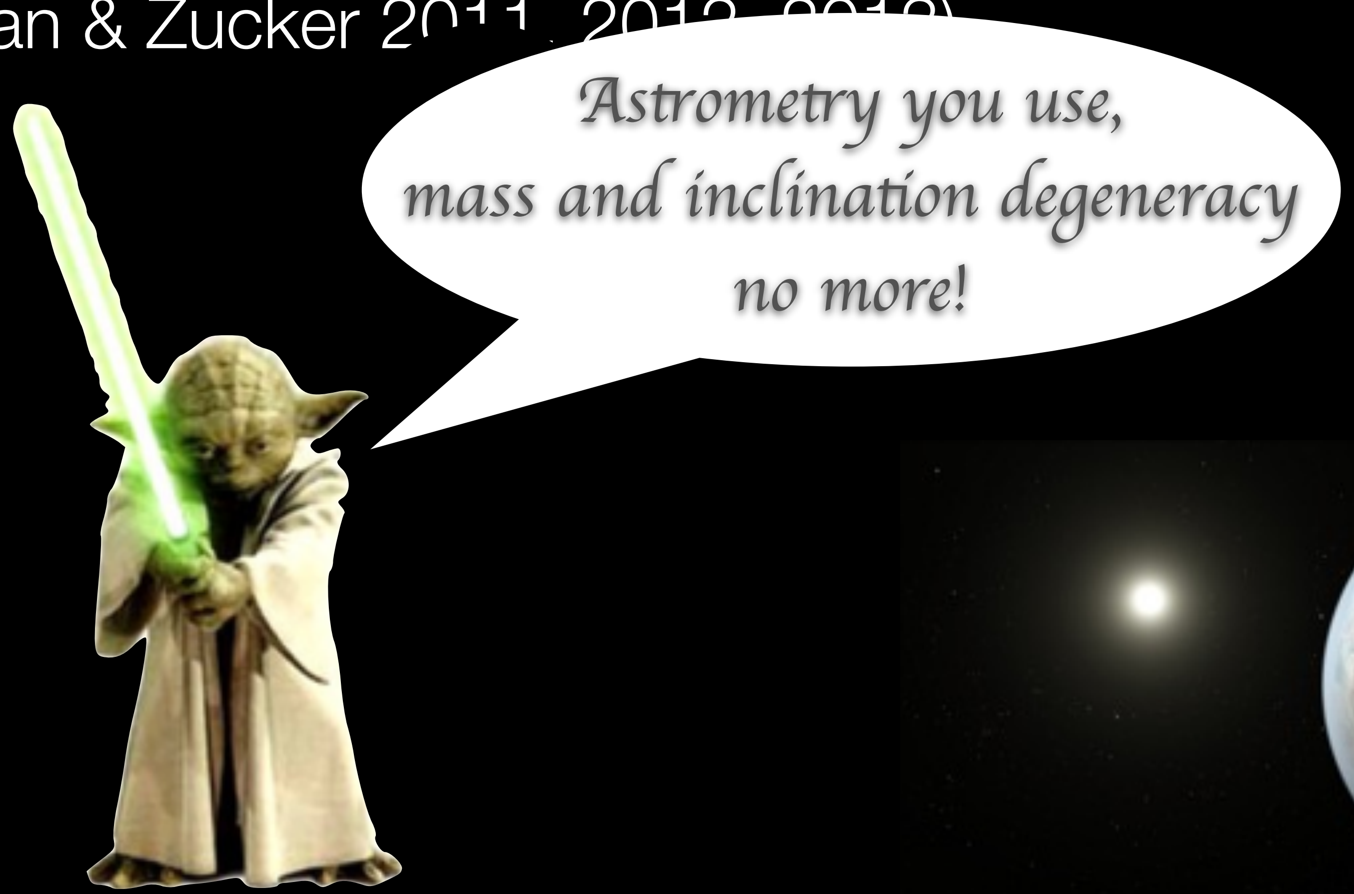
Exoplanet hunting with Gaia

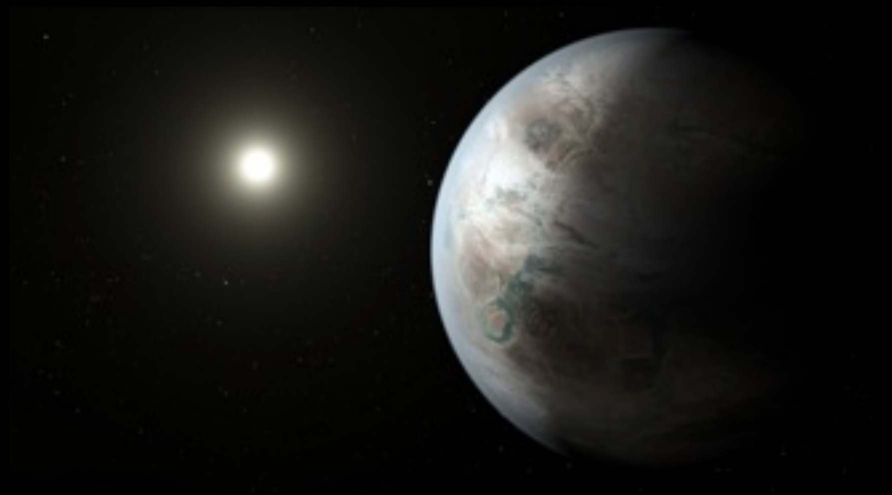


- Accurate mass: no M_p and *sin(i)* degeneracy

- Wide range of host star properties:
  - Mass, Metallicity, Evolutionary stage

- Transit:
  - Astrometrically predicted
  - Directed follow-up (Dzigan & Zucker 2011, 2012, 2013)



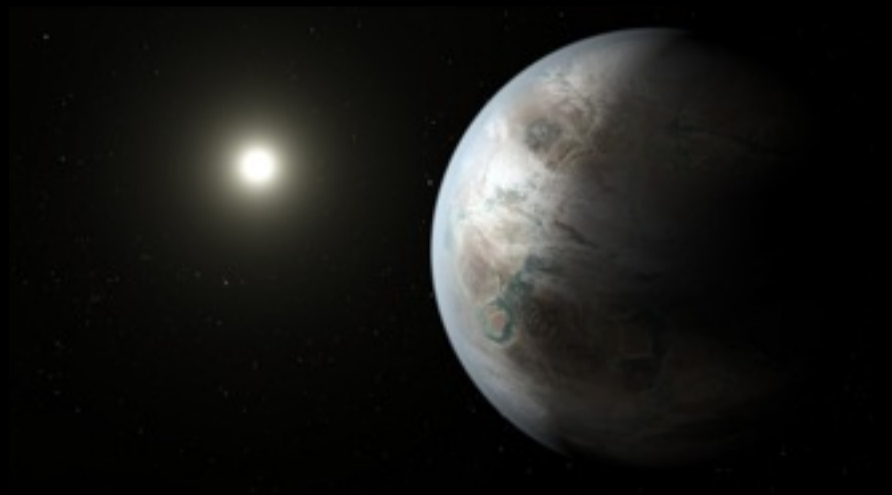


Gaia contributions to exoplanet science

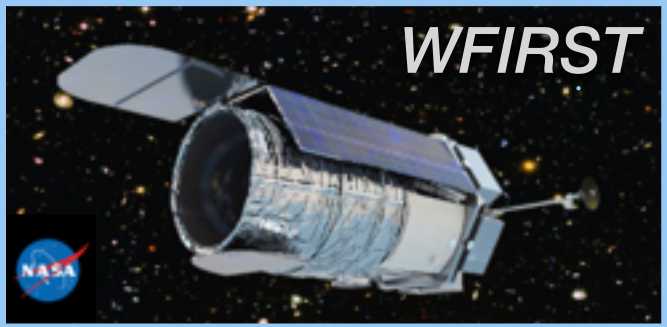
- Stellar characterization:
  - Improved known planet hosts parameters
    - ➡Re-calculate known planet properties
  - Future targets for transit surveys

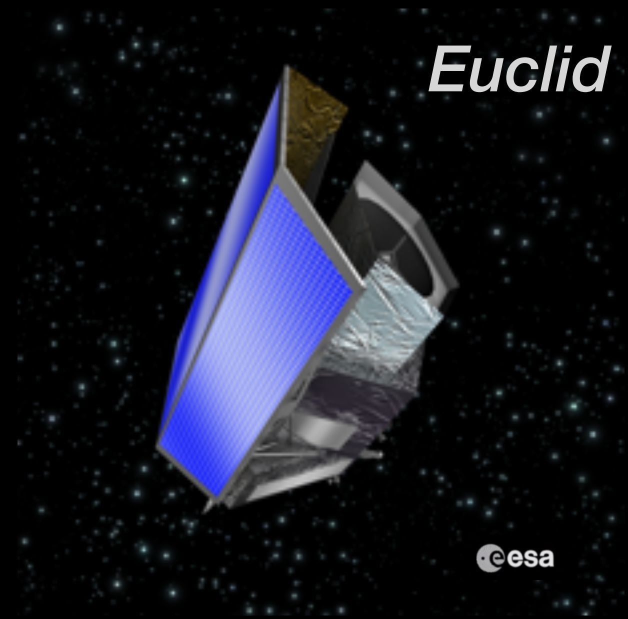
- Astrometric companions to known planetary systems

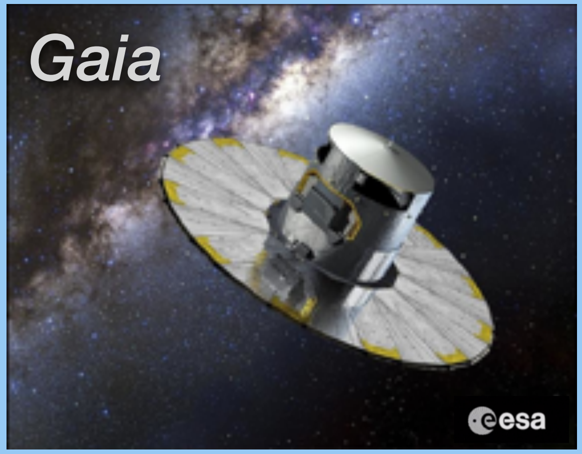
- Brown dwarf companions
  - Wide range in host star parameters



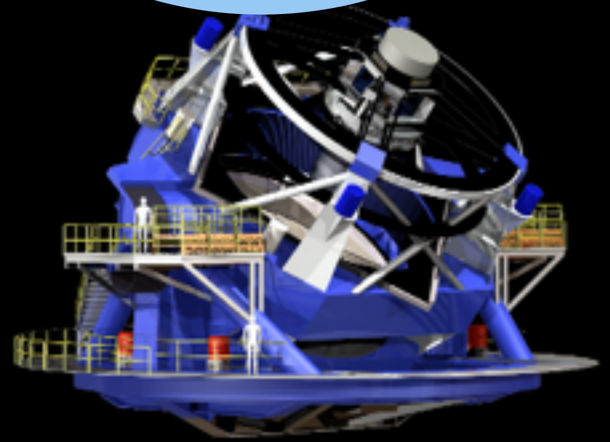
Astronomy in the 2020's



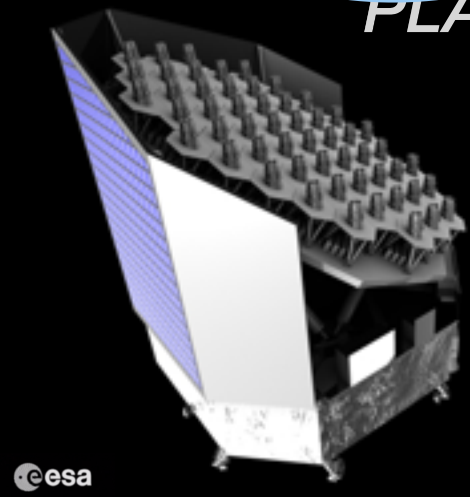




LSST

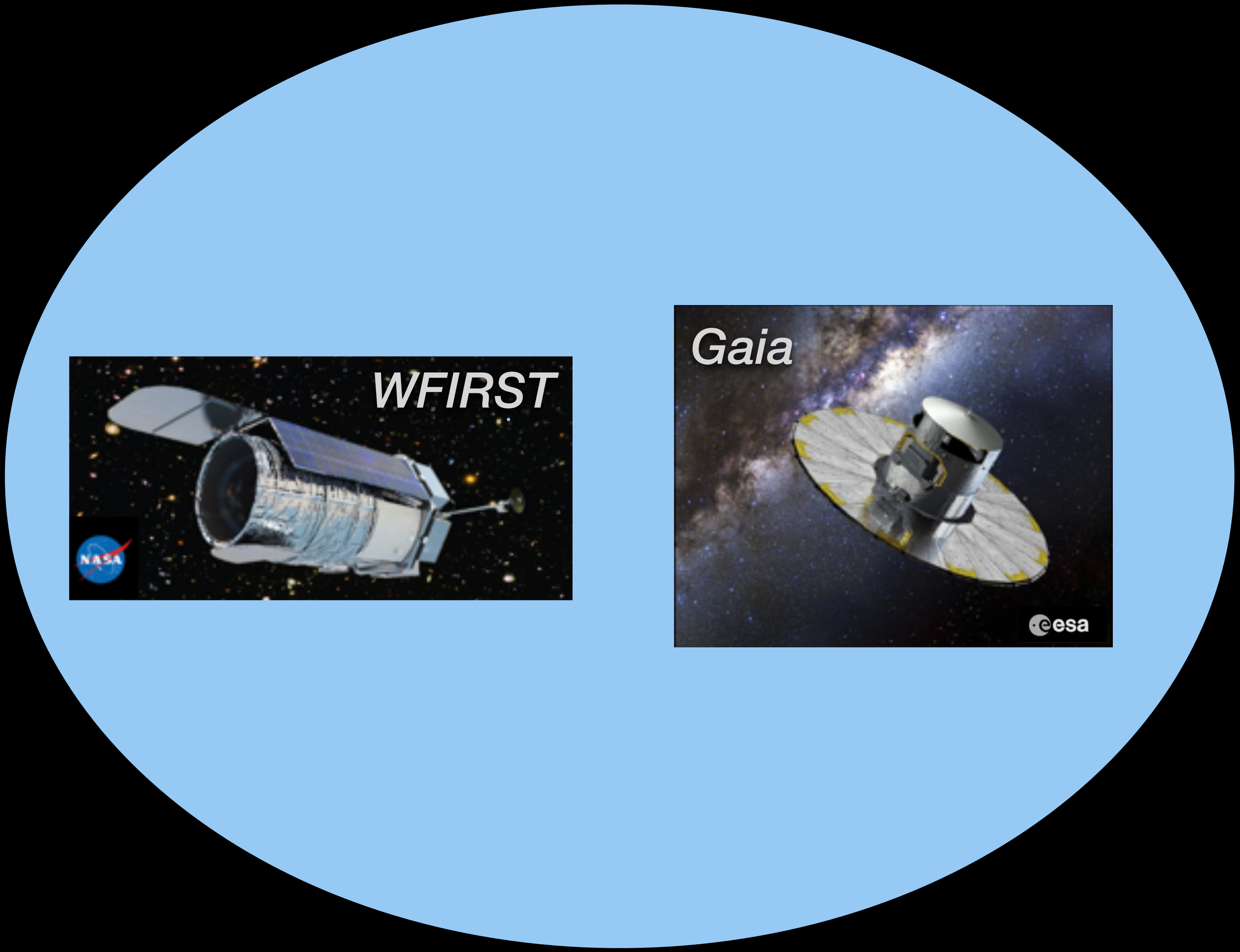


PLATO



Emerging (synergetic) science

"The whole is larger than the sum of its parts"



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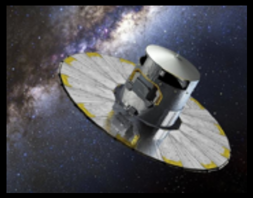
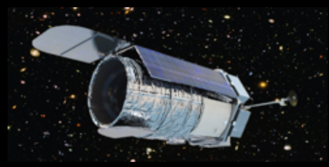


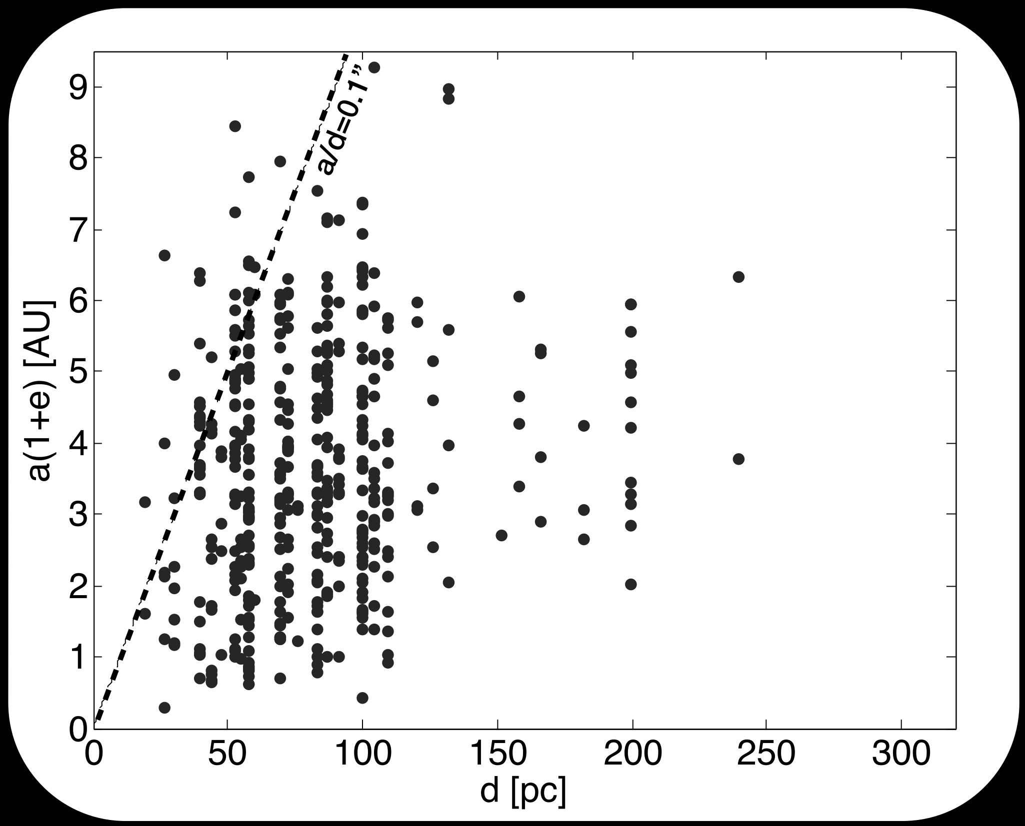
Gaia Exoplanets + WFIRST Coronagraph

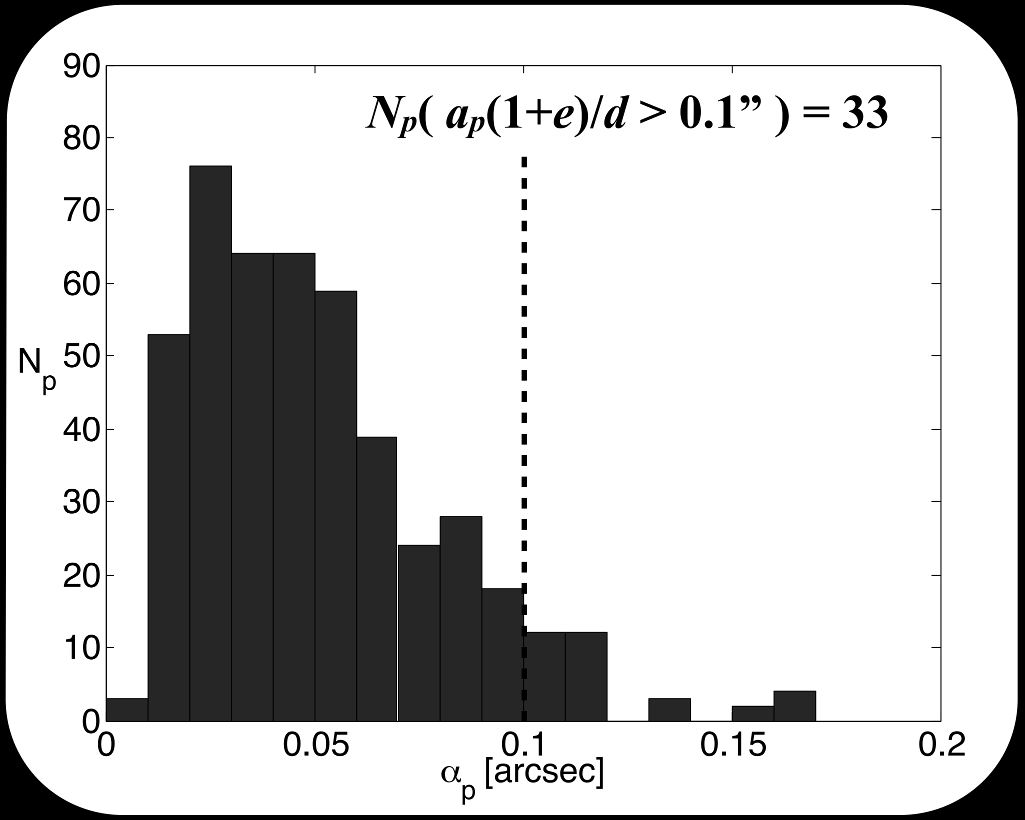


Simulating Gaia data for bright stars

Courtesy Michael Perryman et al.

- *G* < 7 mag
- 0.5 < M_2 < 15 M_J
- 5-year mission
- 0.1” resolution





Reflected-light low-res spectrum of planets with measured mass

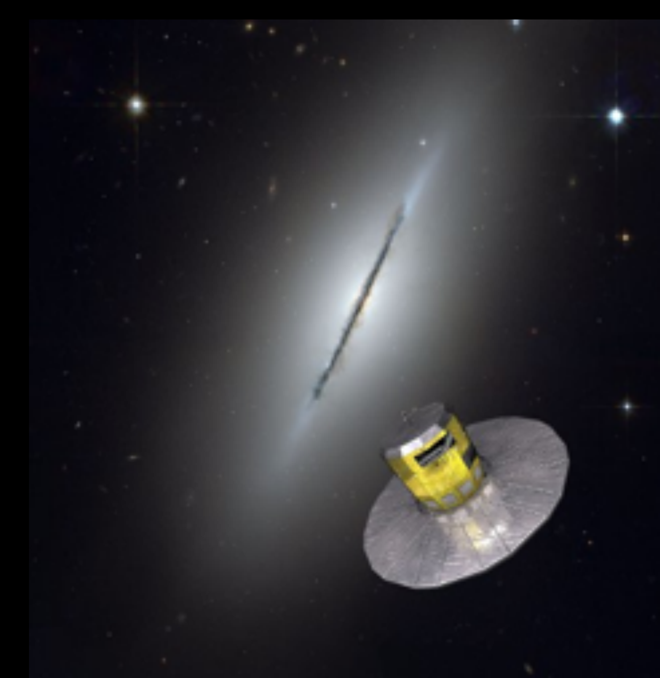
Take Home Message:

Gaia is a game changer in astrophysics and exoplanets

Data release schedule:

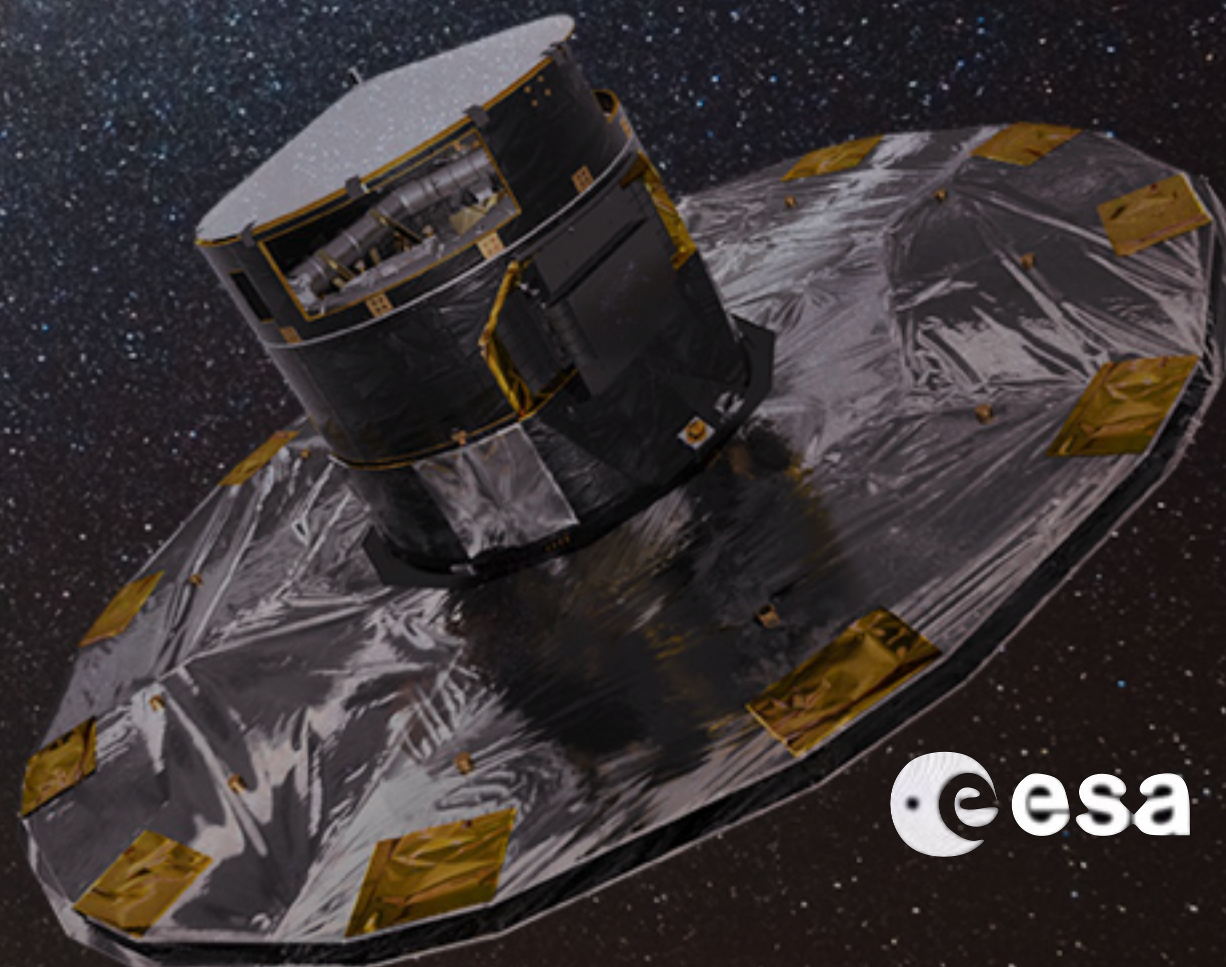
Mid-2016: Positions, G magnitude.

Early 2017: RV, photometry, astrometry.



The Gaia Mission

A billion star map of the galaxy



Resources:

Perryman et al. 2014
Sozzetti et al. 2014
Sozzetti 2011
sci.esa.int/gaia
cosmos.esa.int/web/gaia/
blogs.esa.int/gaia
gaia.ub.edu/Twiki/bin/view/GREATITNFC/

Now available
Gaia App

esa

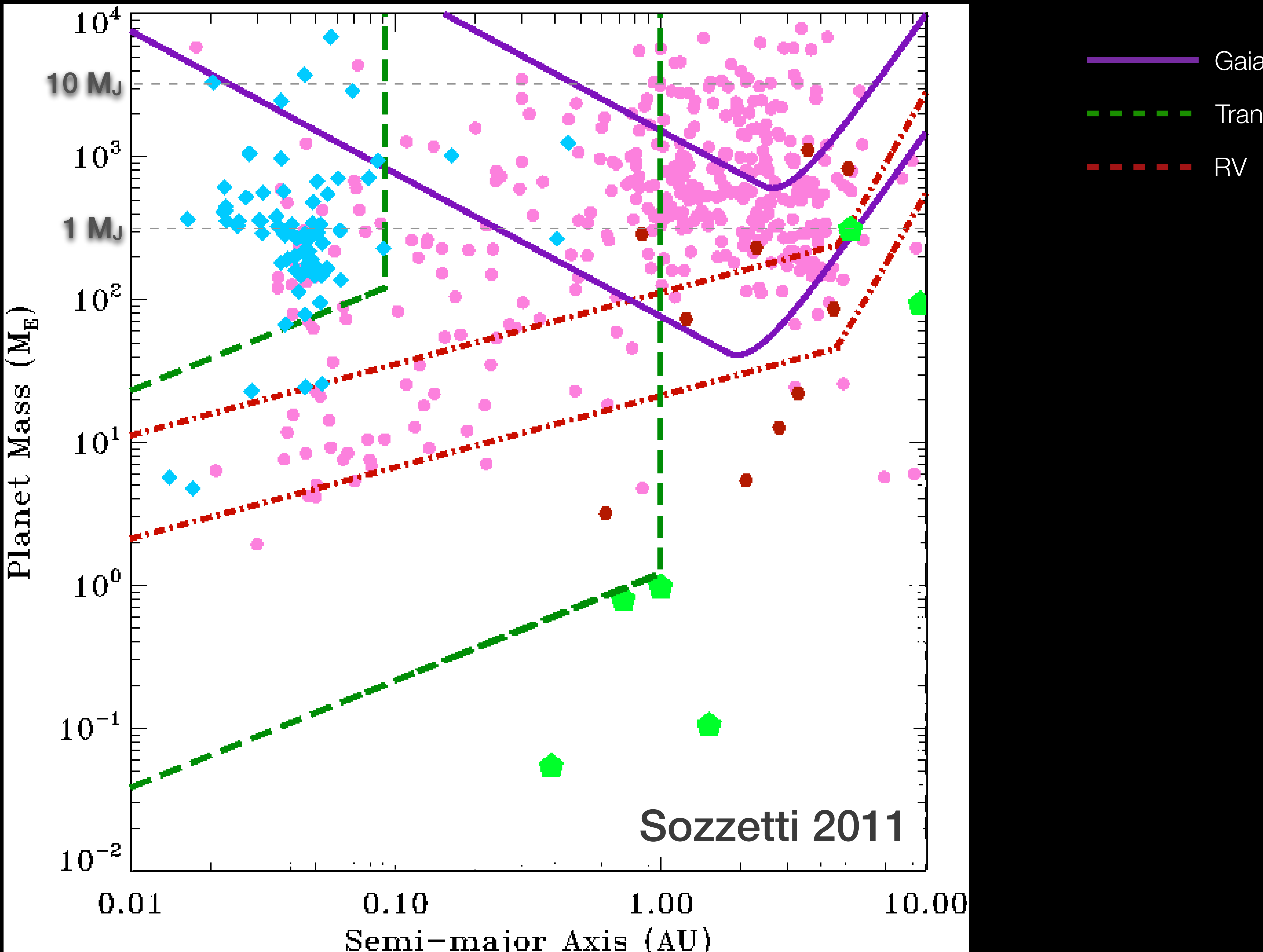
SSW 2015, Pasadena
July 31, 2015

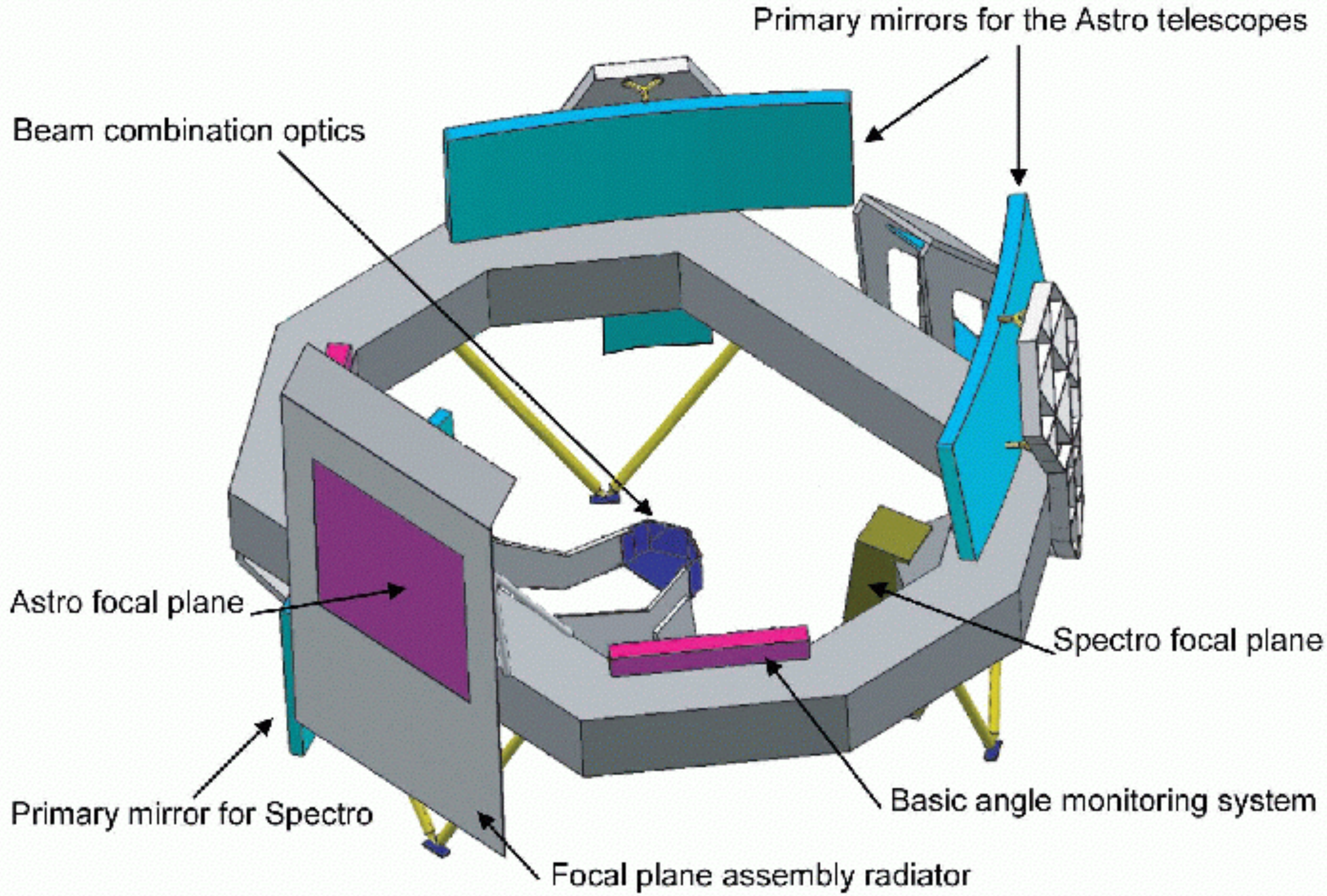
Extra Slides

0.4 M $_\odot$
@ 25 pc

1 M $_\odot$
@ 200 pc

$$\alpha_s \approx \left(\frac{M_2}{\mathrm{M_J}}\right)\left(\frac{M_s}{\mathrm{M_\odot}}\right)^{-1}\left(\frac{a_2}{\mathrm{AU}}\right)\left(\frac{d}{\mathrm{pc}}\right)^{-1} 10^3\ \mu\mathrm{as}$$





Schematic figure of the Gaia payload

Gaia Data Releases (Pre-commissioning)

- Intermediate Data Release Scenario agreed with inputs from Data Release Policy and DPAC Operations Plan
  - Science Alerts as soon as possible
  - L+22m positions, G-magnitudes, proper motions to Hipparcos stars, ecliptic pole data
  - L+28m + first 5 parameter astrometric results, bright star radial velocities, integrated BP/RP photometry
  - L+40m + BP/RP data, some RVS spectra, astrophysical parameters, orbital solutions for short period binaries
  - L+65m + variability, solar system objects

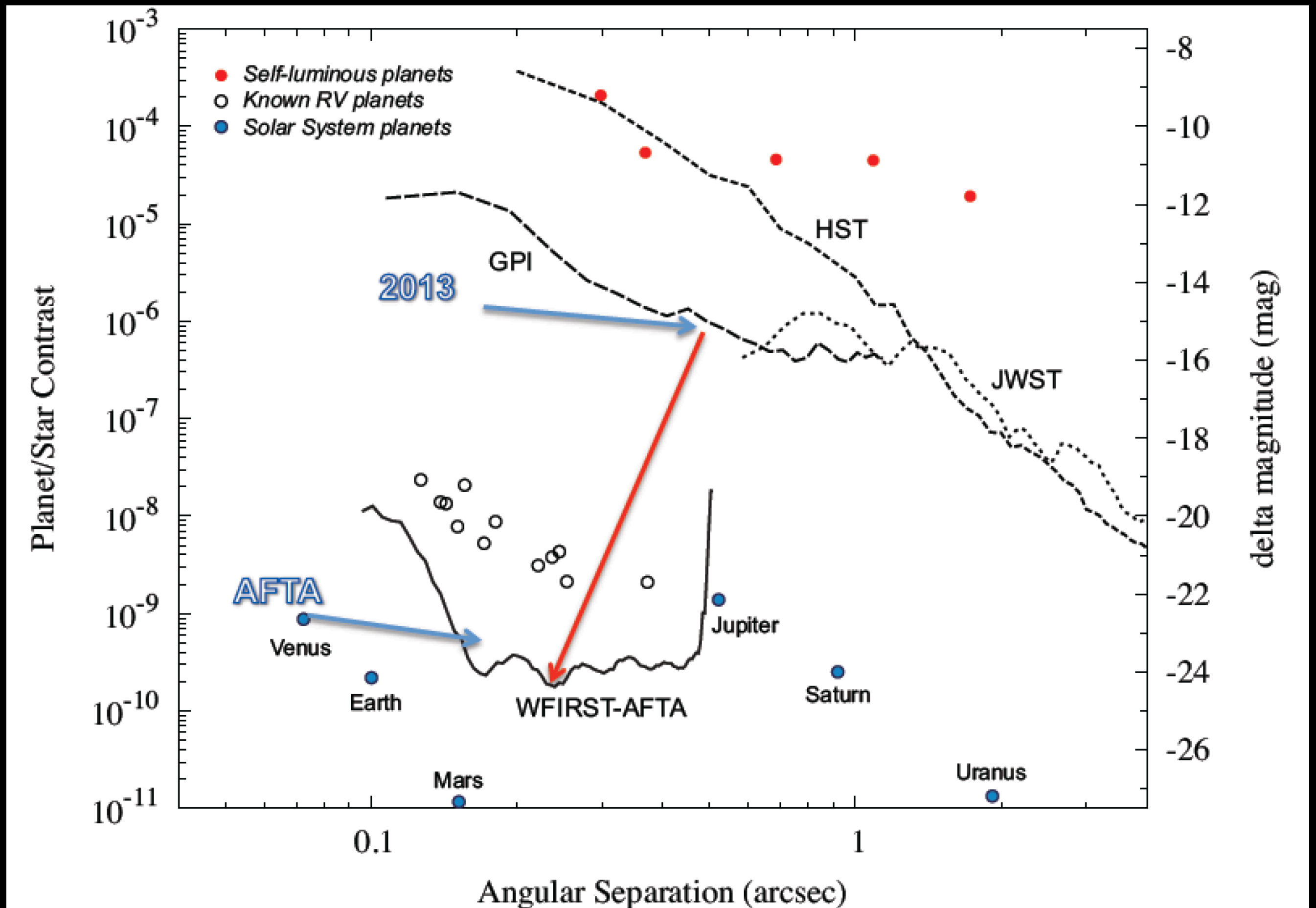
Post-Commissioning: First data release expected by mid-2016

Courtesy Alessandro Sozzetti

WFIRST Coronagraph

- 400 - 1000 nm
- 10^{-9} contrast
- 0.1 arcsec @ 400 nm
- IFS: R~70

$$6 \times 10^{-8} \left(\frac{R_2}{R_J}\right)^2 \left(\frac{a_2}{\mathrm{AU}}\right)^{-2}$$



WFIRST-AFTA SDT Interim Report

★ Gas and ice giant planets in reflected light

  ★ Characterize planetary atmospheres

★ Test technology for future terrestrial planet imaging mission

WFIRST

WFIRST-2.4 coronagraph

Bandpass	400-1000 nm	Measured sequentially in five 18% bands
Inner Working Angle	100 mas	at 400 nm, 3λ/D driven by challenging pupil
	250 mas	at 1 μm
Outer Working Angle	1 arcsec	at 400 nm, limited by 64x64 DM
	2.5 arcsec	at 1 μm
Detection Limit	Contrast=10^{-9}	Cold Jupiters. Deeper contrast looks unlikely due to pupil shape and extreme stability requirements.
Spectral Resolution	70	With IFS
IFS Spatial Sampling	17 mas	This is Nyquist for λ = 400 nm

Table 3-3: Key coronagraph instrument characteristics

Precursor Observations

- LBT-I observations of dust around nearby stars will greatly leverage WFIRST-AFTA disk imaging
  - LBT-I gives total area & mass, adding WFIRST-AFTA gives grain reflectance/albedo
- More ground-based radial velocity (RV) measurements are needed; masses of planets are critical for understanding WFIRST-AFTA spectra
  - Working to evaluate completeness of specific WFIRST-AFTA candidate stars
- Coronagraph science would benefit greatly from having more known RV planets with measured masses (*m* sin *i*) by launch date:
  - A list of known planets will make WFIRST-AFTA much more efficient for detection and characterization
  - RV investments are valuable now for WFIRST: orbits and masses take years
- GAIA astrometry mission will also provide masses in addition to RV

Gaia 2D stellar density sky map (not an image!)