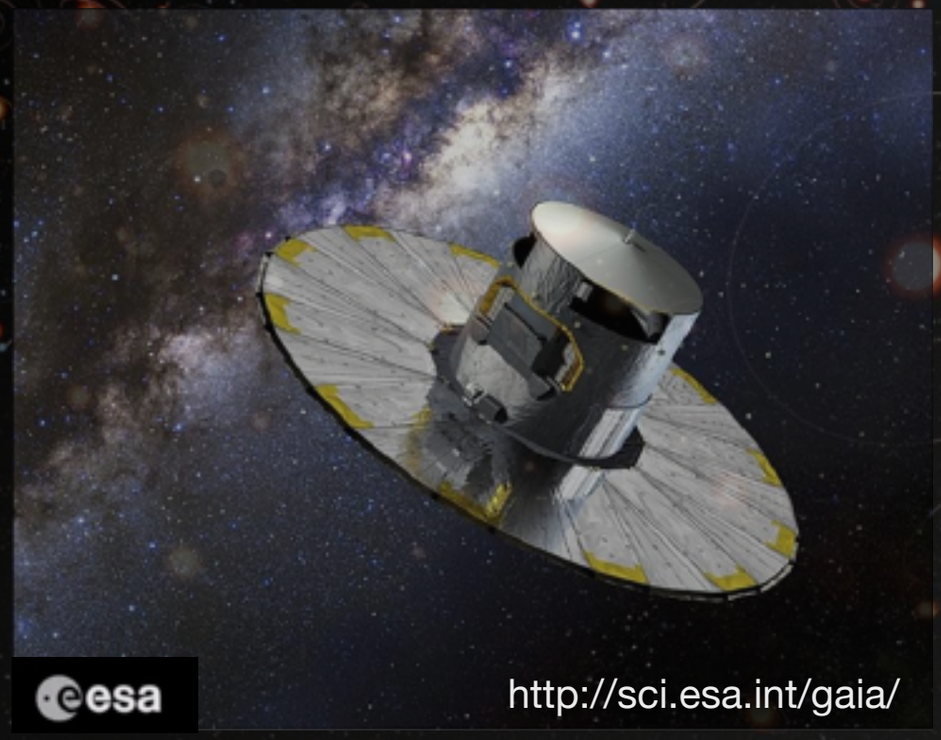
Exoplanet synergies between WFIRST and Gaia

Avi Shporer
Sagan Fellow, JPL

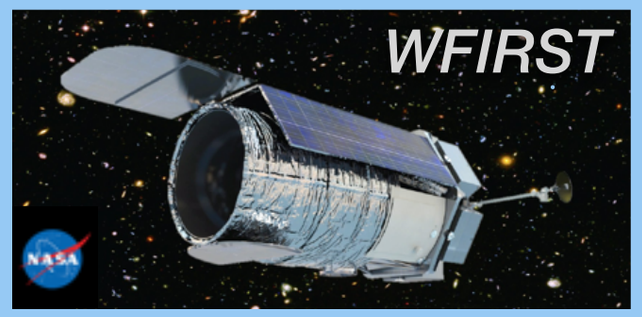


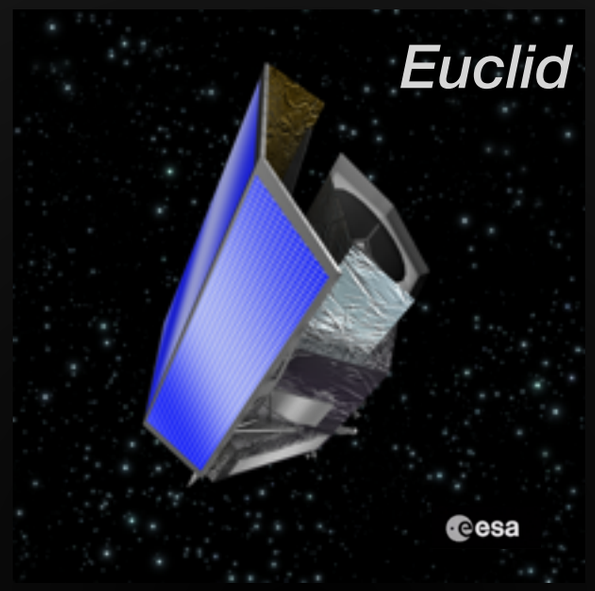
WFIRST

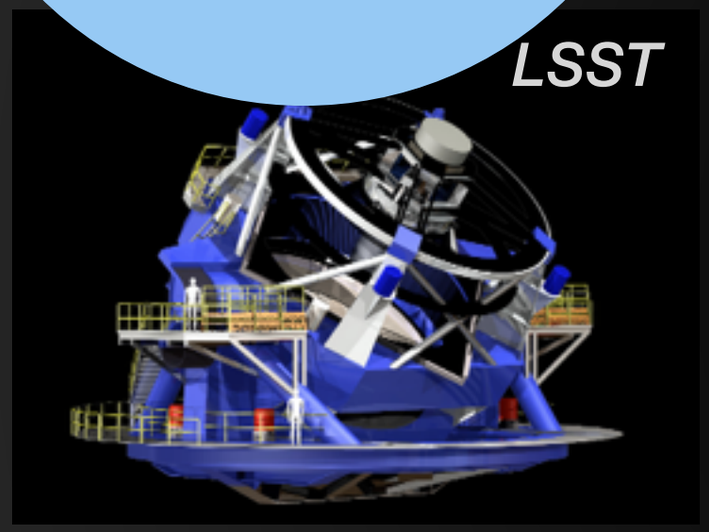
gaia

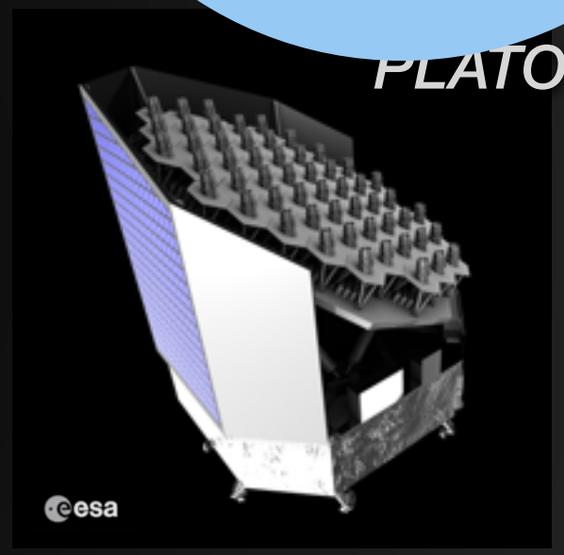
WFIRS 2014, Pasadena
NOV 18, 2014

Astronomy in the 2020's



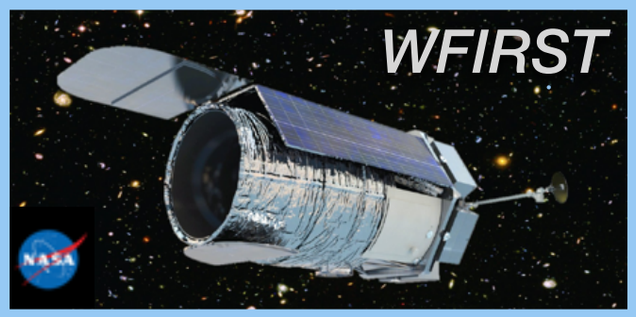


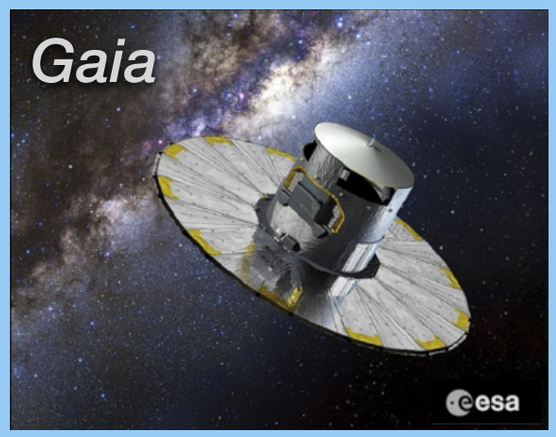




Emerging (synergetic) science

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





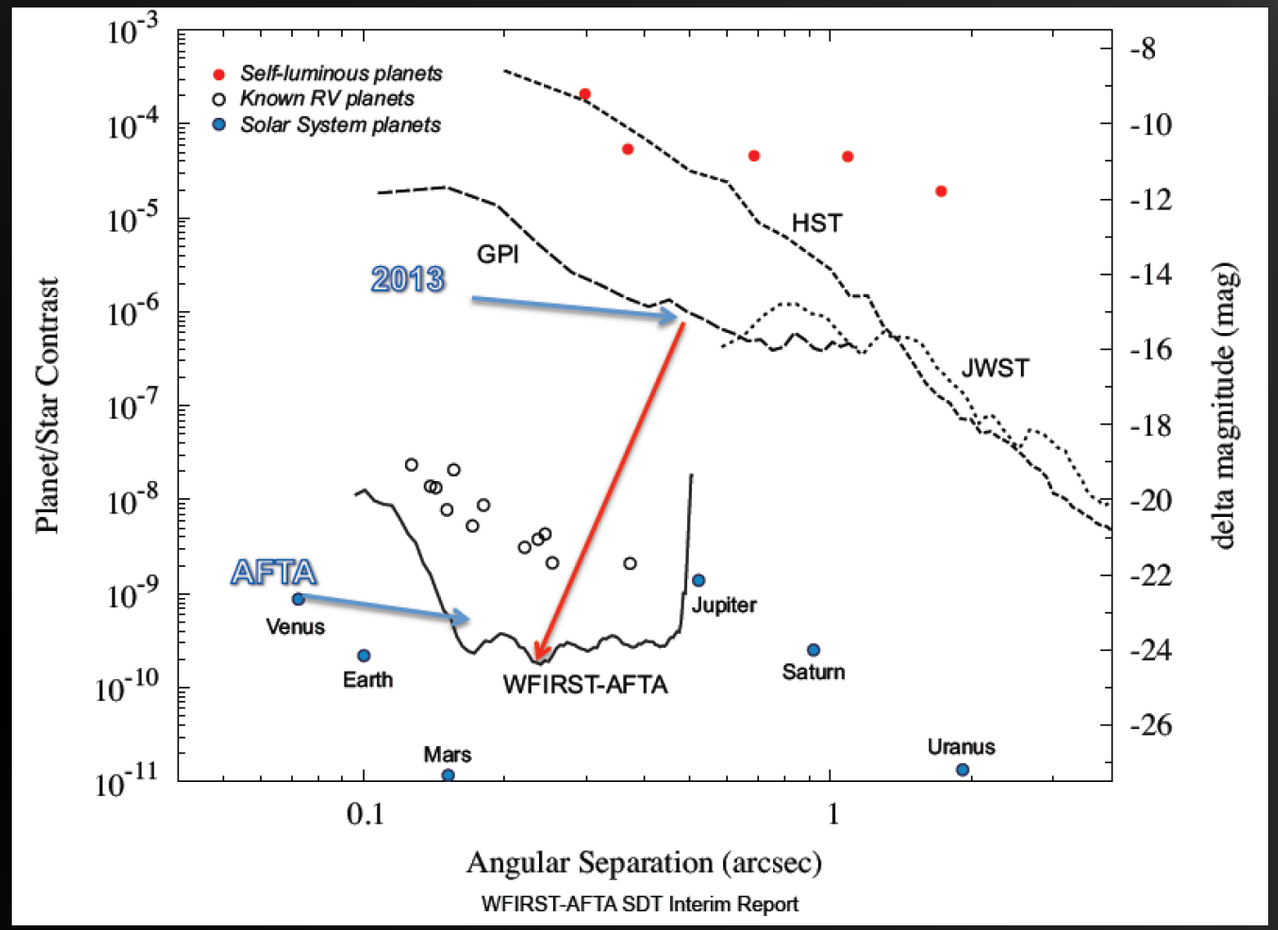
Emerging (synergetic) science

“The whole is larger than the sum of its parts”

WFIRST Coronagraph

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

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



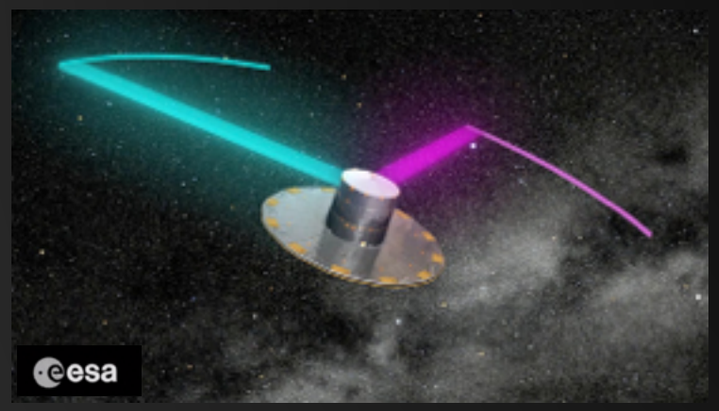
★ Gas and ice giant planets in reflected light
  ★ Characterize planetary atmospheres
★ Test technology for future terrestrial planet imaging mission

WFIRST

Gaia

- Launch: December 2013, L2 orbit
- 50-110 epochs in 5 years (2014-2019) + 5 years extended mission (?)

- 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



See also Gerry Gilmore's Talk, Wednesday 10:50

“Astrometric exoplanet detection with Gaia”

Perryman, Hartman, Bakos, Lindegren 2014

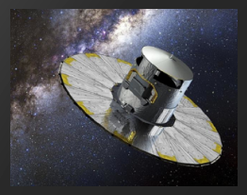
http://arxiv.org/abs/1411.1173

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 S/N 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 ($\pm$6000) high-mass ($\sim 1-15 M_{\rm J}$) long-period planets should be discovered out to distances of $\sim$500 pc for the nominal 5-yr mission (including at least 1000–1500 around M dwarfs out to 100 pc), rising to some 70 000 ($\pm$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.

- Planets with measured mass and orbit
- Wide range in:
  - stellar host mass
  - evolutionary state



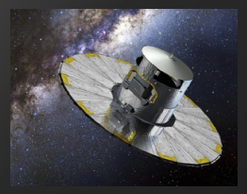
Gaia Exoplanets + WFIRST Coronagraph

Gaia planets simulation for bright stars
Courtesy Michael Perryman et al.

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

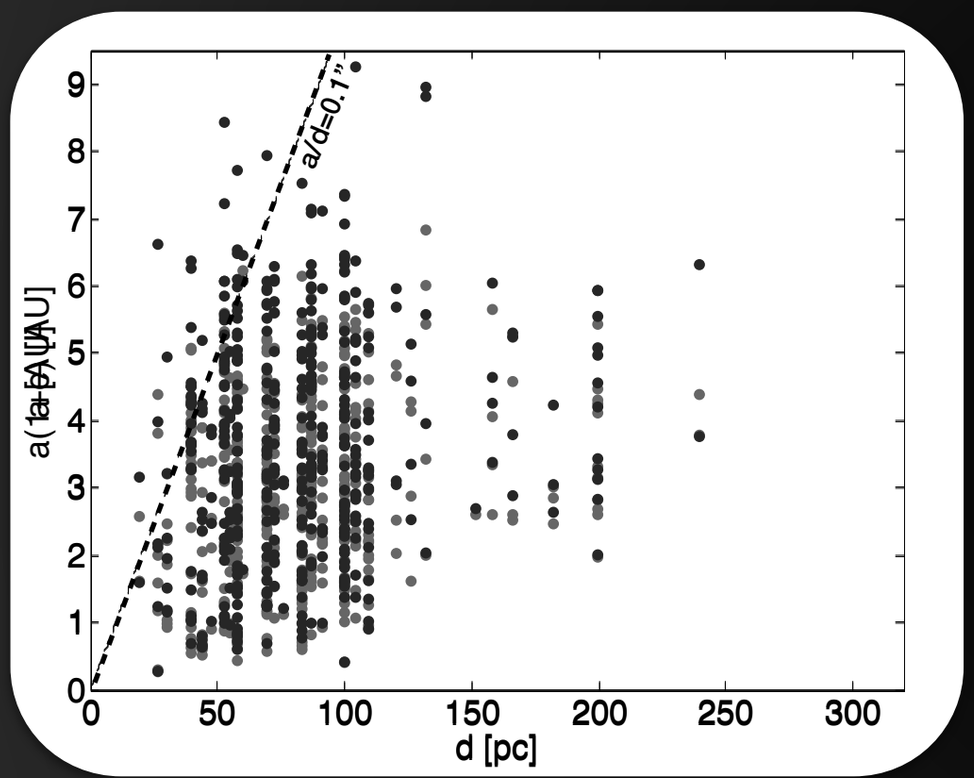
For bright stars:

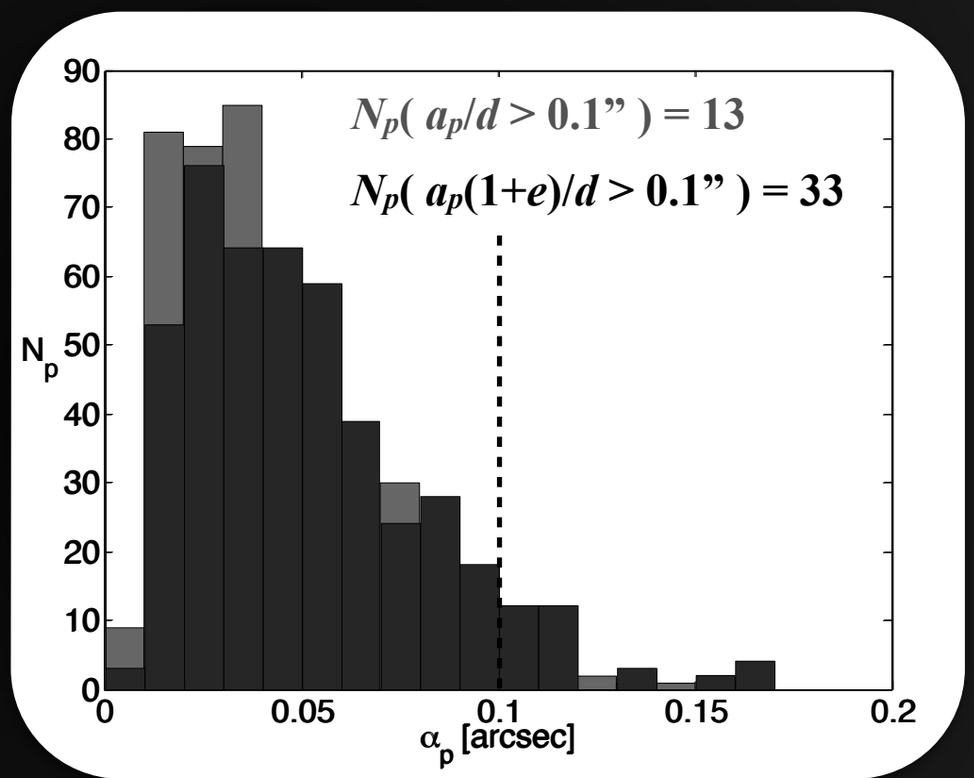
- single measurement $\sigma_{fov} \approx 30$ μas,
- parallax $\sigma_\omega \approx 10$ μas



Gaia Exoplanets + WFIRST Coronagraph

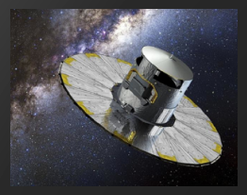
Gaia planets simulation for bright stars
Courtesy Michael Perryman et al.





- $G < 7$ mag
- $0.5 < M_2 < 15$ M_J
- 5-year mission
- Potential transit(!)

➡ Reflected-light low-res spectrum of planets with measured mass
➡ Guaranteed-detection targets, known pre-launch



Gaia + WFIRST

Predicted microlesning events

e.g., Lepine & Di Stefano 2012, Di Stefano et al. 2013, Sahu et al. 2014

Predict microlensing events from Gaia astrometry:

- Lens characterization pre-event
- Simultaneous WFIRST and ground-based observations, get π_E (e.g., Gould 2013)

Gaia resolution: ~0.3“ ⇨ proper motion ≳0.03 “/yr

G [mag]	σ_{fov} [μas]	σ_{ω} [μas]
10	34	11
15	82	26
20	967	300

Pre-event astrometry

Gaia astrometry ⇐ WFIRST microlensing event

WFIRST

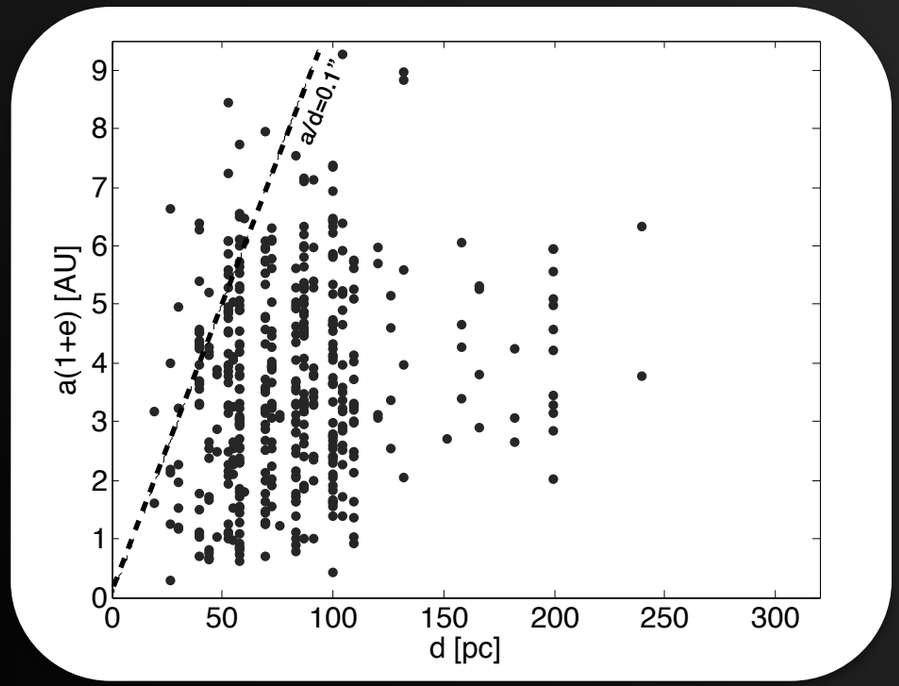
Exoplanet synergies between WFIRST and Gaia

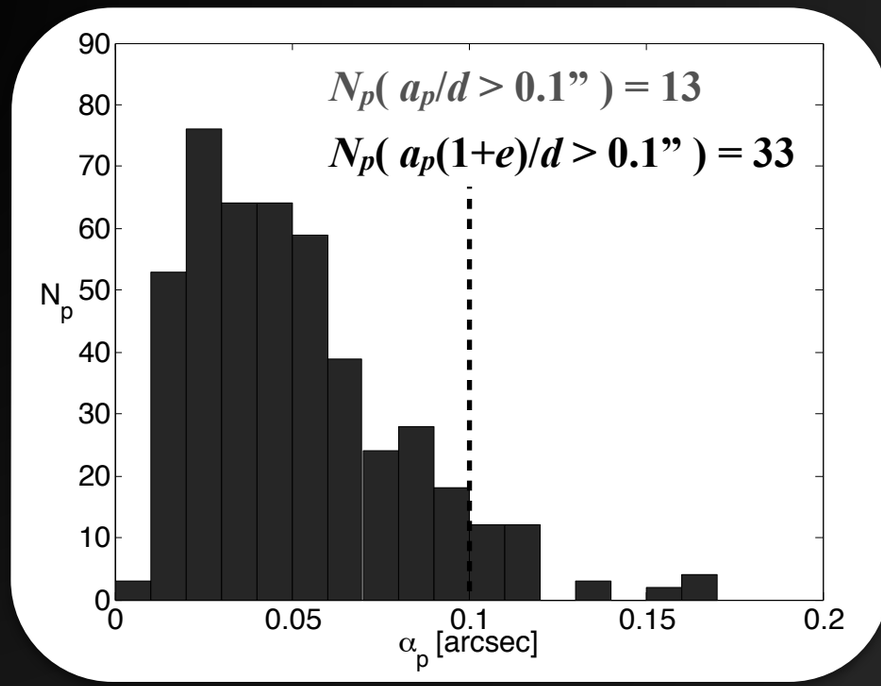
Summary:

- Planets with measured mass
- Guaranteed “emerging science”

Stepping-stone towards imaging of Earth-like planets and biomarkers detection

- Predicted microlensing events
- Pre-event astrometry





Extra Slides

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 require-ments.
Spectral Resolution	70	With IFS
IFS Spatial Sampling	17 mas	This is Nyquist for λ = 400 nm

Table 3-3: Key coronagraph instrument characteristics

Gaia Performance

http://www.cosmos.esa.int/web/gaia/science-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

Stray light science impact (G2V star)

Pre-launch predictions

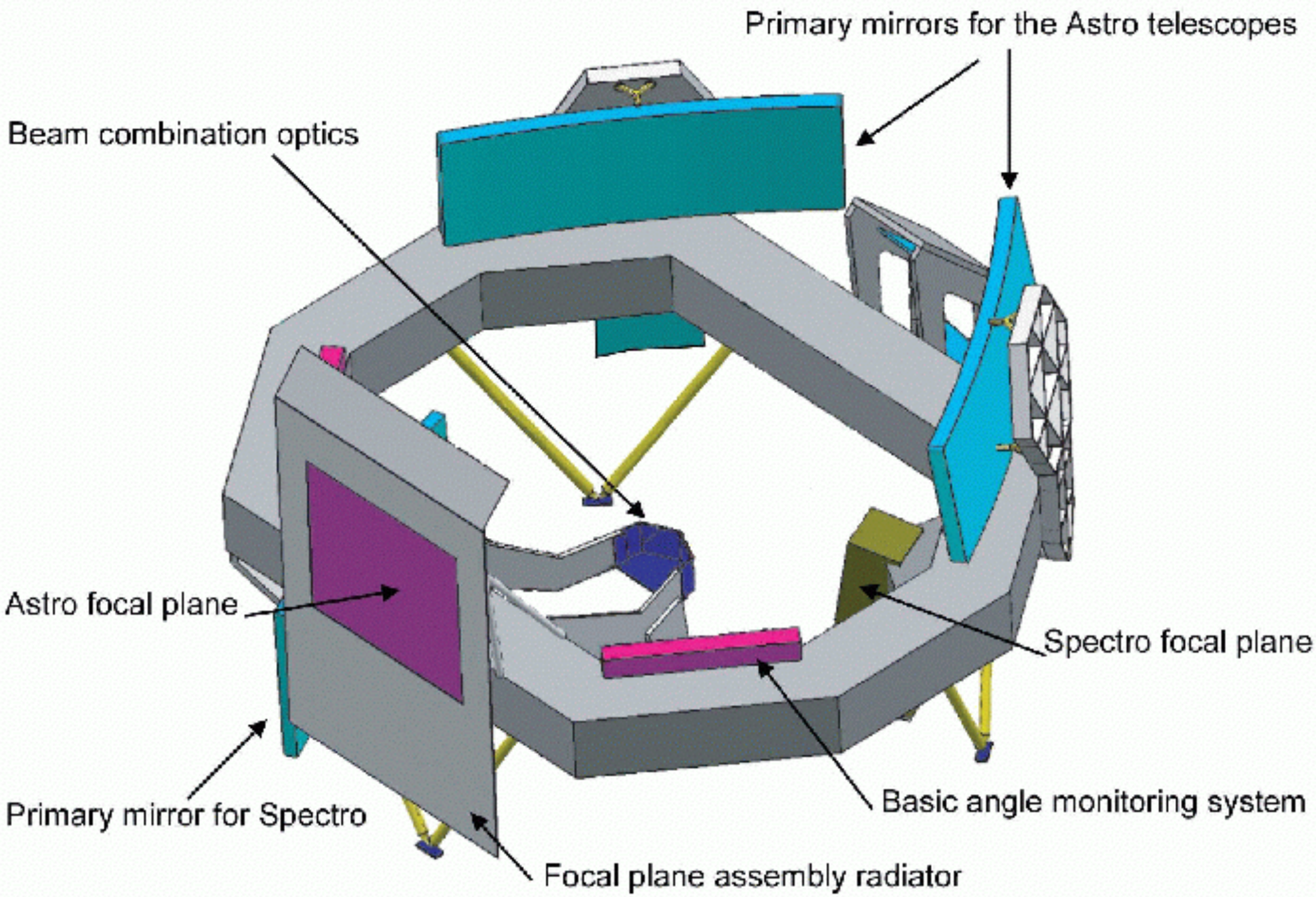
V-magnitude	Astrometry (parallax)	Photometry (BP/RP integrated)	Spectroscopy (radial velocity)
3 to 12	5-14 μas	4 mmag	1 km/s
15	24 μas	4 mmag	3 km/s
16.5			13 km/s
20	290 μas	40 mmag	

Stray light impact (noise contribution only)

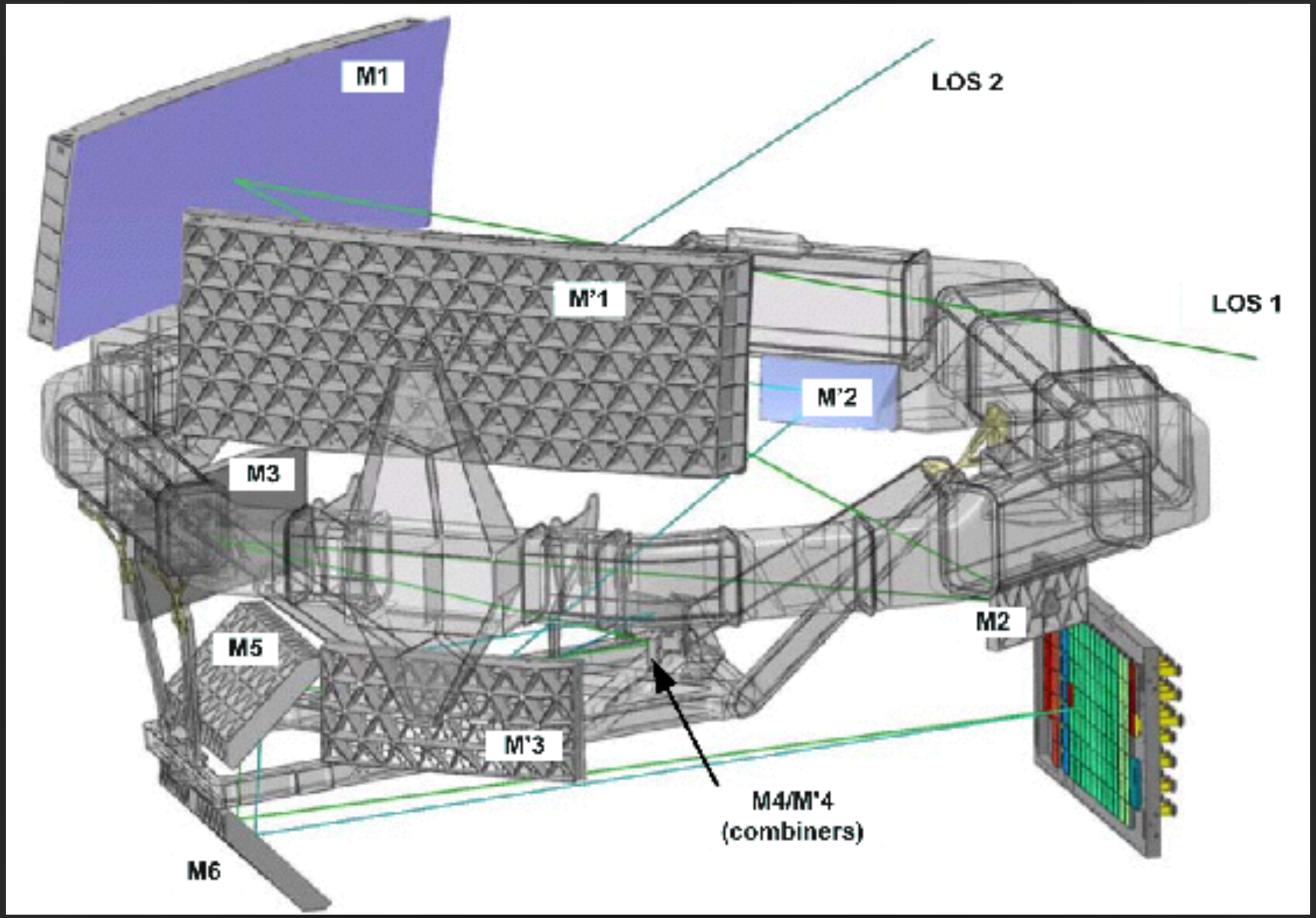
3 to 12	5-14 μas	4 mmag	1 km/s
15	26 μas	5 mmag	13 km/s
16.5			
20	540 μas	60 (RP) – 80 (BP) mmag	

Calculations by: D. Katz, C. Jordi, L. Lindegren, J. de Bruijne

Courtesy Alessandro Sozzetti



Schematic figure of the Gaia payload


M1
LOS 2
LOS 1
M'1
M'2
M3
M5
M'3
M2
M4/M'4
(combiners)
M6

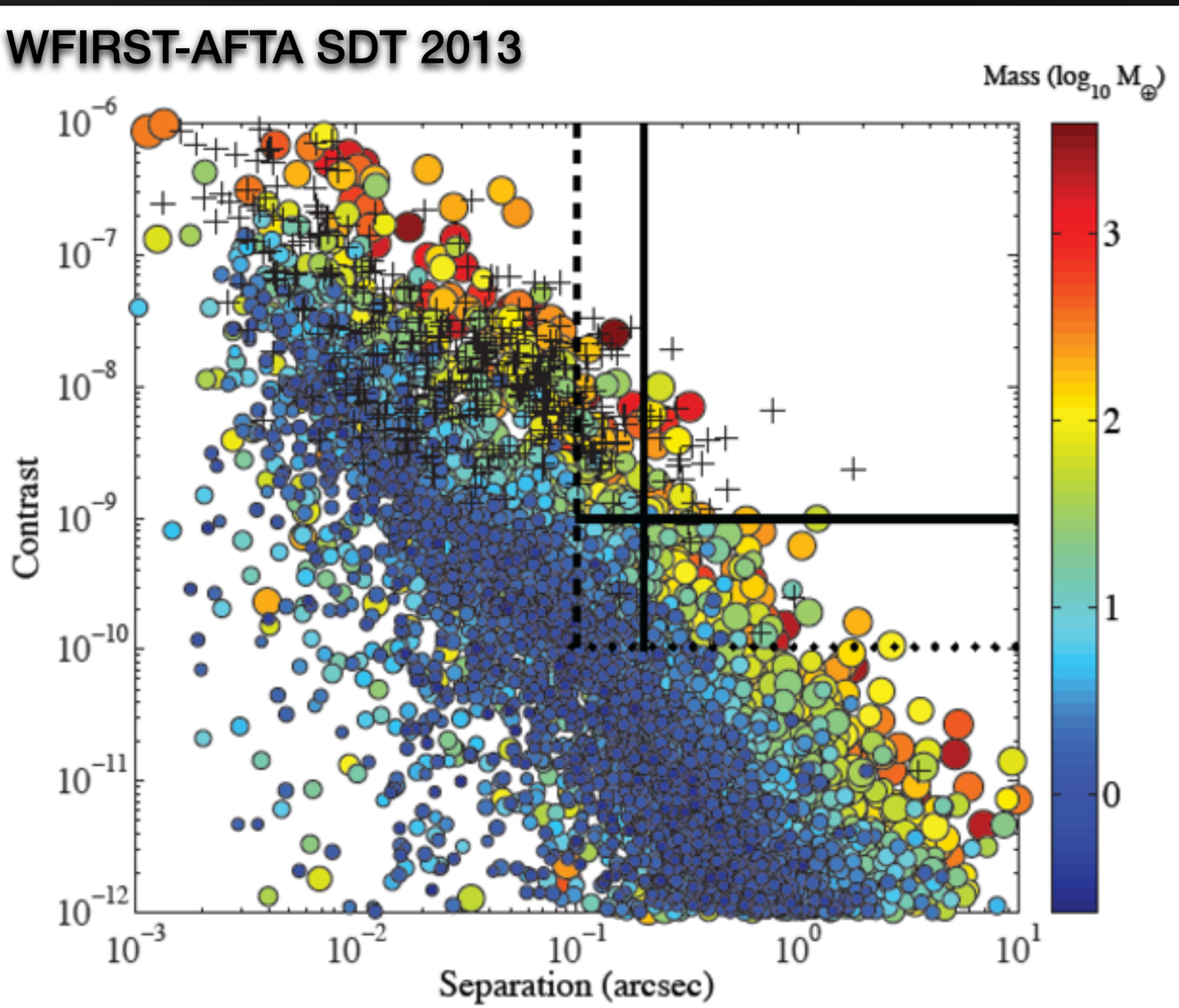
Gaia Data Releases (Pre-commissioning)

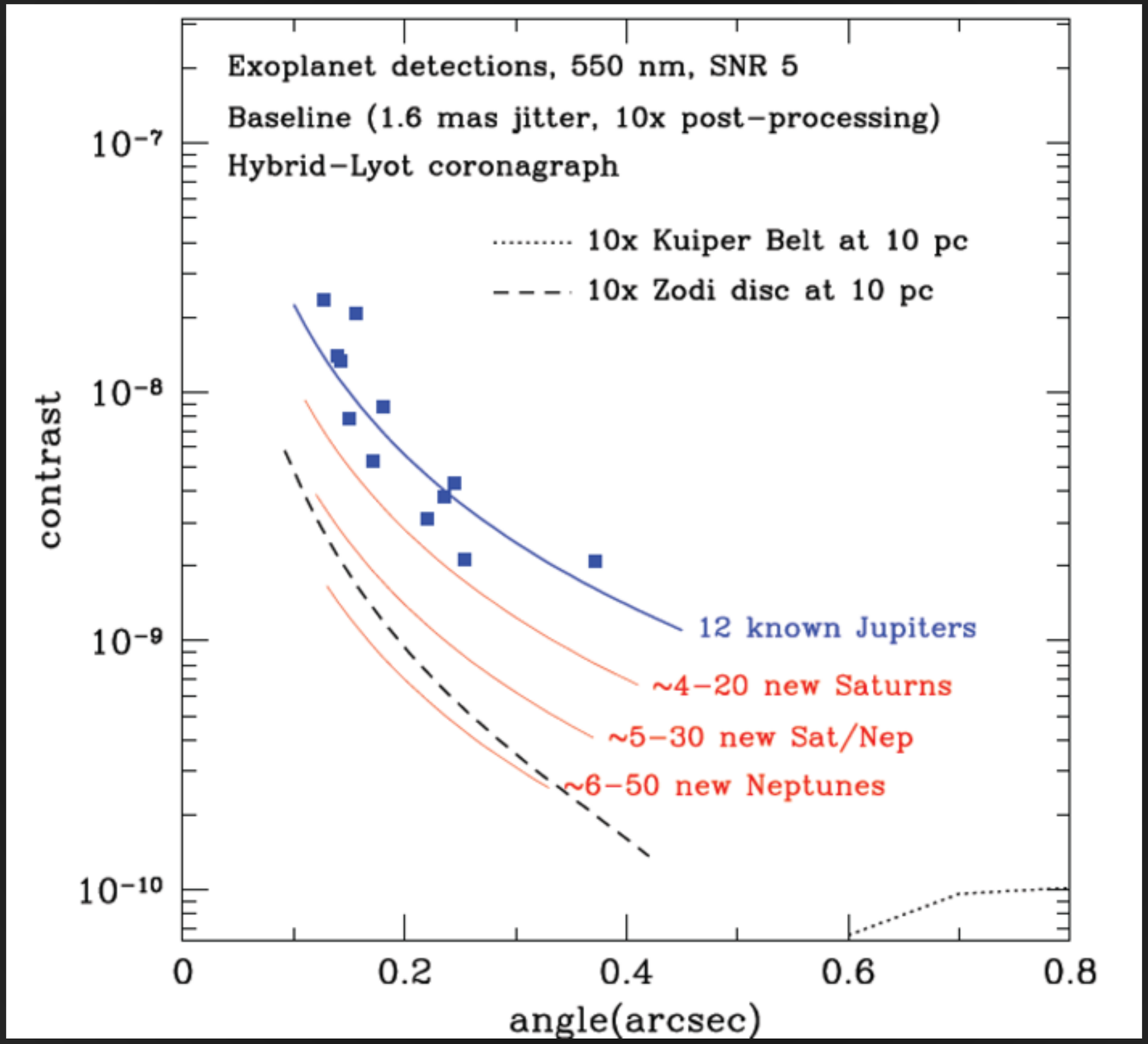
- Intermediate Data Release Scenario agreed with inputs from Data Release Policy and DPAC Operations Plan
  - Science Alerts as soon as possible
  - L+22m positions, G-magnitudes, proper motions to Hipparcos stars, ecliptic pole data
  - L+28m + first 5 parameter astrometric results, bright star radial 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-AFTA SDT 2013




Exoplanet detections, 550 nm, SNR 5
Baseline (1.6 mas jitter, 10x post−processing)
Hybrid−Lyot coronagraph
10x Kuiper Belt at 10 pc
10x Zodi disc at 10 pc
12 known Jupiters
~4−20 new Saturns
~5−30 new Sat/Nep
~6−50 new Neptunes
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
contrast
0
0.2
0.4
0.6
0.8
angle(arcsec)

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