The Gaia mission in the rapidly-evolving context of exoplanet science

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The exoplanet revolution

Mayor et al. (2014)
The exoplanet context

Winn & Fabrycky (2014)
**α Cen B b:** $M=1.1\, M_\oplus$; $P=3.2\, d$ (Dumusque et al. 2012)

**Kepler-10 b:** $M=3.3\, M_\oplus$; $R=1.5\, R_\oplus$ (Batalha et al. 2011)
OGLE-2005-BLG-390: $M=5.4 \, M_\oplus$  
(Beaulieu et al. 2006)

V391 Peg b: $M=3.2 \, M_J$; $P=3.2 \, yr$  
(Silvotti et al. 2007)

Planetary system around HR 8799  
(Marois et al. 2010)
Kepler statistics shows that (Fressin et al. 2013)...

- 2% of stars have Jupiters
- 22% have Neptunes
- 20% have super-Earths
- 16% have Earths

50% of stars have planets of some type

Howard (2013)
### 1,826 Confirmed Exoplanets

**Temperature**

- **Mercurians** (10^5 — 0.1 M⊕)
  - Hot: 3 (0.2%)
  - Warm: 0 (0%)
  - Cold: 0 (0%)
- **Subterrans** (0.1 — 0.5 M⊕)
  - Hot: 15 (0.8%)
  - Warm: 0 (0%)
  - Cold: 0 (0%)
- **Terrestrial** (0.5 — 2 M⊕)
  - Hot: 106 (5.8%)
  - Warm: 1 (0.1%)
  - Cold: 1 (0.1%)
- **Superterrans** (2 — 10 M⊕)
  - Hot: 504 (27.6%)
  - Warm: 20 (1.1%)
  - Cold: 7 (0.4%)
- **Neptunians** (10 — 50 M⊕)
  - Hot: 333 (18.2%)
  - Warm: 12 (0.7%)
  - Cold: 17 (0.9%)
- **Jovians** (> 50 M⊕)
  - Hot: 498 (27.3%)
  - Warm: 105 (5.8%)
  - Cold: 190 (10.4%)

**Stellar Systems**

- 668
- 315
- 100
- 33
- 13
- 4
- 1

*Some of the potentially habitable exoplanets are still unconfirmed.*

[CREDIT: PHL @ UPR Arecibo (phl.upr.edu) Sep 2014]
The Solar System is not the norm

Circumbinary planets

Kepler 16 b, Kepler 34 b, Kepler 38 b, PH1 b...

The orbit of HD80606 b is as eccentric as that of Halley’s comet

Planets with inclined or retrograde orbits

“Lava planets”

$T > 2500$ K

Corot 7b, Kepler 78b, 55 Cnc e, Kepler 10b....
Mayor et al. (2014)
- Multiple planetary systems are common
- Low mutual inclinations!

- One: 2,117
- Three: 134
- Five: 18
- Seven: 1
- Two: 384
- Four: 48
- Six: 2

Lissauer et al. (2014)
Kepler-11
(Lissauer et al. 2011)
• Atmospheres of transiting planets can be probed
• Physical properties (T-P), chemical composition, hazes, clouds

GJ 1214 b (Kreidberg et al. 2014)
**Timeline**

- First exoplanet around a “normal” star: 1995
- First transiting exoplanet: 1997
- First atom detected in atmosphere: 1999
- First molecule in atmosphere: 2001
- First rocky exoplanet: 2003
- Kepler discoveries: 2005
- First rocky exoplanet: 2007
- First rocky exoplanet: 2009
- First rocky exoplanet: 2011
- First rocky exoplanet: 2013

**Yesterday...**

Detection: Hot Neptunes & SuperEarths
Characterization: Hot Jupiters

**Today...**

Detection: Mild SuperEarths around M stars
Characterization: Hot Neptunes & SuperEarths around M stars

**Tomorrow...**

Detection: Mild SuperEarths around GK stars
Characterization: Mild SuperEarths around GK stars

**Soon...**

Detection: Mild Earths around GK stars
Characterization: SuperEarths around GK stars

**RV:** ~1 m s\(^{-1}\)  
**Phot:** ~100 ppm

**RV:** ~10 cm s\(^{-1}\)  
**Phot:** ~10 ppm
Instrument timeline

- CoRoT
- Kepler - K2
- HARPS
- HARPS-N
- HIRES
- SOPHIE
- TESS
- NGTS
- MEarth-S
- “Warm” Spitzer
- HST
- VLT
- “Warm” Spitzer
- HST
- E-ELT
- SPICA?
- GAIA
- CHEOPS
- JWST
- E-ELT
- SPICA?
- Now - 2014
- 2017
- 2020
- PLATO 2.0 2024
- ESA L-mission?

- HIRES
- CRIRES, FORS, FLAMES, K-MOS, SPHERE
- NGTS
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• First S-class ESA mission
• Launch in 2017
• What CHEOPS will do:
  ➢ 1-step characterisation of super-earths & neptunes
    by measuring accurate radii & bulk densities for such planets orbiting bright stars
  ➢ Golden targets for future atmospheric characterisation
    by finding the planets most amenable to deep atmospheric studies
• How CHEOPS will do it:
  ➢ High-precision photometry
  ➢ Observing bright stars anywhere
  ➢ Targets provided by ground-based RV & transit planets, or K2 & TESS
• NASA mission (2017)
• Moon-resonant HAO
• Staring for 27 days
• Bright stars
• Full sky (1 + 1 year)
PLATO

- M-class ESA mission
- Launch in 2024
- 6 years @ L2
  - 2 long pointings of 2-3 years
  - Step-and-stare phase (2-5 months)
- 32+2 cameras

- 2250 deg² per field
- 42% of sky
• Detection & bulk properties of terrestrial exoplanets in the HZs of solar-type stars
• Thousands of rocky, icy or giant planets, architecture of their planetary systems ⇒ formation and the evolution of planets

• Will focus on bright stars (V=4–11/13)
• $10^6$ light curves
• 85000 stars with asteroseismology (M, R, age)
...and GAIA!
• No single reliable astrometric discovery so far (from the ground)
• Gaia will change this: >10^4 planets (Casertano et al. 2008; Perryman et al. 2014)
  – 3D orbits of planets
  – Mutual inclinations
  – Planets around massive stars, evolved stars, young stars, and other types of stars with low Doppler or transit precision

Perryman et al. (2014)
• Complementary discovery space with transit surveys
• Gaia will also discover a few $10^2$-$10^3$ planets depending on follow-up strategy (Dzigan & Zucker 2012, 2014)
• Beyond planet discoveries the impact of Gaia will be tremendous on exoplanet science:
  ➢ Characterization of planet host stars:
    – Distance and chemical composition
    – Cross-check of asteroseismic ages & distances
    – d and L, together with $T_{\text{eff}}$ (from, e.g., HR spectra), will yield stellar radii with 1-2% uncertainty
    – Census for RV surveys (e.g., nearby M dwarfs)

Dzigan & Zucker (2012)
The revolution continues!...