Class 4

Exoplanets

Key points
- Difficulty of direct imaging
- Gaia astrometry
- Kepler
- General properties of exoplanets

Direct imaging:

Extreme contrast

Planet radius R_p; orbit distance a; albedo A; reflects a fraction

$$f = \frac{A \cdot \pi R_p^2}{4\pi a^2}$$ of the incident flux

Incident stellar flux $F_\star$

Planet intercepts $F_\star \cdot \left(\frac{\pi R_p^2}{4\pi a^2}\right)$ → Reflects $A F_\star$

$$\frac{\text{Planet Flux}}{\text{Stellar flux}} = \frac{A}{4}\left(\frac{R}{a}\right)^2$$ redo? Shouldn't it be corrected by $R_\odot$?

$$f = 1.4\times10^{-10}\left(\frac{A}{0.3}\right)\left(\frac{R_p}{R_\odot}\right)^2\left(\frac{a}{1\,AU}\right)^{-2}$$

$$f = 1.4 \times 10^{-10} \left(\frac{A}{0.3}\right) \left(\frac{R_p}{R_\oplus}\right)^2 \left(\frac{a}{1\,AU}\right)^{-2}$$

24 magnitudes fainter than host stars.

Analog planets 10 pc away

By thermal emission — Approximate as black body:

Flux ratio

$$f = \left(\frac{R_p}{R_*}\right)^2 \frac{\left(e^{h\nu/kT_*} - 1\right)}{\left(e^{h\nu/kT} - 1\right)}$$

At 20 μm where Earth peaks (300 K);

$$f \sim 10^{-6}$$

Better, but need more resolution.

resolution

$$\theta \sim 1.2 \frac{\lambda}{D} \qquad D = 1.2 \frac{\lambda}{\theta}$$

to achieve 0.5 AU at 5 pc; (0.1 arcsec), in the visible ($\lambda = 5500$ Å); then

$D = 1.5\ m$

For $\lambda = 20\ \mu m$; $\boxed{D = 50\ m}$!

JWST = 6m

Easier to image giant planets at large separations (like HR 8799)

Gaia (Astrometry)

$$a_* = \frac{M_p}{M_*} \cdot a \qquad \text{(motion of star)}$$

$\theta \cdot d$ $\quad \therefore \quad \theta = \frac{M_p}{M_*} \cdot \frac{a}{d}$

Gaia may be able to detect tens of thousands of exoplanets out to 500 parsecs.

Gaia: 10 μas (13 V)

500 μas (20 V)

Astrometry

$$\theta = 500 \left(\frac{M_p}{M_J}\right) \left(\frac{M_*}{M_\odot}\right)^{-1} \left(\frac{a}{5\ AU}\right) \left(\frac{d}{10\ pc}\right)^{-1} \mu as$$