Outline

- What is an exoplanet?
- Why do we care?
- Detecting exoplanets
- Exoplanets compared to planets in the solar system
- Exoplanet atmospheres
What is an Exoplanet?

- An exoplanet is a planet outside our solar system (Also called an extrasolar planet)

- The first exoplanet was discovered in the early 1990s

- To date over 450 exoplanets have been discovered
Why do we Care?

• We are continually trying to answer the following questions:
  • Is the Earth and our solar system common in the universe?
  • Are there other planets that might be habitable?
  • Can we detect indicators of life?
How do we Detect Them?

• Several ways:
  • Doppler Method
  • Transits
  • Directing Imaging
  • Astrometry, Microlensing, and Others...
Doppler Shift Detections

- The light from a star is shifted slightly in wavelength due to the velocity of the star.
- As a planet orbits a star, the velocity of the star will oscillate.
- Larger planet = larger effect.
- Close to star = easier to find.
Transit Detections

- If the planet's orbit is oriented just right, it can pass in front of the host star.
- We can detect the slight drop in the star's brightness.
- Larger planet = larger signal.
- Closer to star = more likely.
Direct Imaging

- In some cases we can directly photograph an exoplanet
- Works well with large planets far from their host star
Are Exoplanets like the Solar System?

- We still don't know
- Selection bias has favored very large planets, often very close to their host star
- There has been some very surprising discoveries...
Transit Doppler Imaging
Hot Jupiters

- Massive planets up to 10 $M_J$ ($M_J = 1.9 \times 10^{27}$ kg or about 300 Earths)
- Often closer to their star than Mercury
- Very Hot: 1000-2000 K
- High temperatures cause large atmospheric scale heights
Atmosphere Types

• What do we expect atmospheres to be like?
• Highly mass dependent:
  - Dominated by H and He – planet must be large so that these light elements won't escape
  - H-rich atmospheres – planets in the range of 10-30 Earth masses that are not too hot could have a mixture of H2 as well as gases from outgassing. May be dominated by H2, H2O and CH4 or CO.
Atmosphere Types

Outgassed Atmospheres – Planet not large or cold enough to keep its H. Likely to be CO2 dominated.

Hot Super Earths – High temperature has caused H, N, C, O and S to all escape. A thin atmosphere may contain silicates.

No Atmosphere – Mercury and the moon are good examples of this
Studying Exoplanet Atmospheres

- How can we study the atmosphere of a planet that is light years away?
- Eclipses are Key:
  - **Primary Eclipse**
    - Measure size of planet
    - See star's radiation transmitted through the planet atmosphere
  - **Secondary Eclipse**
    - See planet thermal radiation disappear and reappear
    - Learn about atmospheric circulation from thermal phase curves
Discoveries so Far

• About a dozen exoplanet atmospheres have been observed so far.
• Only hot Jupiters have been studied in a significant way.
• Interpreting observations are often heavily based on models.
• Largely based on two space telescopes: *Hubble* and *Spitzer*.
Discoveries so Far

- Large IR emission – confirms that atmospheres are exceedingly hot.
- Implies efficient absorption of visible light
- Albedos less than about 0.2 (Earth = 0.37, Jupiter = 0.5)
- Several species have been detected:
  - Na, CH4, CO, CO2, H2O
- H2O mixing ratio $\sim 10^{-4}$
Transmission spectrum of planet around HD 189733

- Binned model, water + methane
- Binned model, water + methane + ammonia
- Binned model, water + methane + carbon monoxide
- Observations

Absorption (%) vs. Wavelength (μm)
Thermal emission of planet around HD 189733
CO2 in the Atmosphere

- The abundance of CO2 in the atmosphere of a Hot Jupiter was a surprise (CO2 may be much larger than expected in one hot Jupiter studied).

- CO2 is in equilibrium with CO:

  \[ \text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2 \]

- But at high temperatures and with H2 dominating the atmosphere CO is expected to be much more abundant than CO2.
CO2 in the Atmosphere

- It is likely that in this case photochemistry plays a significant role:
- CO2 is also produced by OH:
  \[ \text{CO} + \text{OH} \rightleftharpoons \text{CO}_2 + \text{H} \]
- Where OH is from photolysis of H2O:
  \[ \text{H}_2\text{O} + \text{hv} \rightarrow \text{OH} + \text{H} \]
Other Hydrocarbons

There may be trace amounts of hydrocarbons in the atmospheres of Hot Jupiters – C$_2$H$_2$, C$_2$H$_6$ and NH$_3$

Photolysis of CO can make C$_2$H$_2$, CH$_4$ and C$_2$H$_6$

$$\text{CO} + h\nu \rightarrow \text{C} + \text{O}$$
Just In Case you Care:

CH4 Production

\[
\begin{align*}
CO + h\nu & \rightarrow C + O, \\
C + H_2 + M & \rightarrow ^3 CH_2 + M, \\
2^3 CH_2 & \rightarrow C_2 H_2 + 2H, \\
C_2 H_2 + H + M & \rightarrow C_2 H_3 + M, \\
C_2 H_3 + H_2 & \rightarrow C_2 H_4 + H, \\
C_2 H_4 + H + M & \rightarrow C_2 H_5 + M, \\
C_2 H_5 + H & \rightarrow 2 CH_3, \\
CH_3 + H + M & \rightarrow CH_4 + M.
\end{align*}
\]
Other Discoveries

- Transmission spectra provide evidence for haze
  Small particles
- Planets are likely tidally locked
  Day/night temperature differences can be relatively small (200 K) or very large (1000K)
  Strong winds likely
Other Discoveries

• Inversions were not expected with the lack of molecules to efficiently heat the upper atmosphere (O3 for example)

• Tentative evidence for temperature inversions in some hot Jupiters

• Possible absorbers could include TiO or photochemical hazes
Future Research

- Continue to push to discover Earth-like planets or biosignatures
- What would Earth look like with these type of observations
- This would be VERY difficult to observe
Future Research - Biosignatures

- Biosignatures – gas whose abundance is completely out of equilibrium
- Examples:
  - CH4 and O2 (both)
  - Large O2
- Must avoid other possible scenarios (O2 due to sudden loss of oceans)
- Most of the work so far has focused on O2, O3, N2O and CH4
Questions?
References


