Lecture 45: Solar Systems in Comparison

Key Ideas
Our methods are best at detecting massive planets, usually close to the star
Properties of Exoplanets
- "Hot Jupiters"
  - Theories of Formation
  - Atmospheres
  - Tidal Locking
- Eccentric Orbits
- Multiple Planet Systems
  - Weather on a planet
  - Orbital Resonances
- Habitable Zones

Review of Our Solar System
Only terrestrial planets closer than 5 AU
- Mercury -- 0.4 AU
- Venus -- 0.7 AU
- Earth -- 1.0 AU
- Mars -- 1.5 AU
- Jupiter -- 5.2 AU
- Saturn -- 9.5 AU
- Uranus -- 19.2 AU
- Neptune --30.1 AU

Gas giants only form beyond the frost line where ices can help form grains --> planets
Largest eccentricity is Mercury with $e=0.20$. All others have $e < 0.10$

Strange New Worlds
None of the systems found so far resemble the Solar System
The biggest surprise is Jupiter-sized planets so close to their parent stars:
- Many have orbits smaller than Mercury's!
- Deep inside the "Frost Line", where Jupiter-sized planets should not be able to form.

What is going on?

Migration and other ideas
Migration:
- Jovian planets form far from the star
- spiral inwards due to drag from the primordial stellar nebula disk.
- Migration stops at the inner edge of the disk
- Could be more likely in very heavy stellar nebulae

Formation:
- Close Jupiters just formed differently than in our Solar System.
- Might be very different from Jupiter in detail?

Atmospheres of Hot Jupiters
Sudarsky et al. Classification

Name	Semi-major axis	Temperature	Atmosphere	Examples
Class I Jovian	a > a few AU	T < 150 K	Methane and ammonia clouds	Jupiter, Saturn, 47 UMa c
Class II Water	a =1-2 AU	T=150-250 K	Water and Methane clouds	47 UMa b, υ And d (at apastron)
Class III Gaseous	a=0.2-1 AU	T=350-850 K	Few clouds	Gliese 876b?
Class IV Close-in	a=0.1-0.2 AU	T~1000K	CO, a little methane clouds	55 Cnc b
Class V	a < 0.05 AU	T~14000K	Silicate and Iron Clouds	51 Peg b, υ And b

Tidal Circularization
The lowest energy state is a circular orbit in a 1:1 spin-orbit resonance.
Stops the cycle of squeezing and expanding -- planet stays squeezed the same amount
Expect close-in planets to have circular orbits

Eccentricities of Exoplanets
Close-in planets not always on circular orbits!
Perturbed by another planet?
Highest eccentricity for all planets: e= 0.95
1/2 of planets found so far beyond 1 AU have e>0.30.

Multiple Planet Systems
Current record holder: 55 Cnc
5 planets found by Doppler shifts

Upsilon (υ) Andromadae System
3 planets discovered so far
52 light-years away
1.2 solar mass star
3.6 Gyr old

Weather on upsilon And b
Planet is believed to be tidally locked to the star.
One side is blasted by the star, the other side freezes. **1400K** temperature difference
When daytime side faces Earth -- more emission

Atmosphere does not distribute heat evenly

Orbital Resonances

Migration of planets

- Explain hot Jupiters
- Can put planets in orbital resonances

Examples

- Gliese 876
  - 2:1 orbital resonance
- PSR 1257+12
  - 3:2 orbital resonance

Gliese 581 system

Star: 0.33 solar masses
581b: 15 Earth masses, 0.041 AU
581c: 5 Earth masses, 0.073 AU
581d: 7.7 Earth masses, 0.25 AU

Doppler Wobbles from Smaller Planets

Two things make the Doppler Wobbles bigger

- Bigger mass
- Closer to star

Force of gravity is bigger
Much easier to detect Gliese 581b (top panel)

In the Habitable Zone

- Gliese 581 is a cooler (~3500 K) and smaller (0.38 solar radii) star than the Sun
- Less energy emitted per area
- Habitable zone where water is liquid is closer to the star
- Gliese 581c should be a rocky or oceanic planet with a temperature between 0 and 40 degrees Celsius

The Future

Continuing search for other systems

- Find systems more like our own
- How common are planetary systems?

Future Goals:

- Find Earth-sized planets.
- Find Earth-sized planets in orbits where liquid water is possible
- Search for Life Markers like O_2 & O_3 in their atmospheres