Bit of Administration ....

- **Washburn Observatory**
  - Wednesday, after dusk for a few hours

- **Reading**
  - Chapter 24, Chapter 14 recommended

- **Discussion Section**
  - Web-lecture in advance of section
    - 2 pts extra credit for evaluation
    - 3 pt extra credit quiz
    - responsible for material

- **Final**
  - Sunday, May 9, 12:25-2:25, B102 Van Vleck
Life in the Solar System

• Arguments for Life as High Probability
  • Organic molecules form easily
  • Life occurred quickly on Earth - < 3.85 billion years
  • Life can exist in a wide range of conditions
Life in the Solar System

- Life on Europa?
  - Icy crust
  - Tidal heating

Liquid oceans
Volcanic vents
Extrinsolar Planets

• Key Idea - With present technology, cannot “see” an extrasolar planet due to small angular separation and faintness
  - Observing effects of planet ON star

• Detection Methods
  • Doppler Method - most productive - 110 planets!
    • Radial-velocity variations (discussion section)
  • Astrometric
    • Angular motion of star in the sky
  • Planetary Transits
    • Eclipses
  • Gravitational Lenses
Addison Wesley Astronomy
Extrasolar Planets

Doppler Shift due to Stellar Wobble

Unseen planet
Extrasolar Planets
PLANETS AROUND NORMAL STARS

INNER SOLAR SYSTEM

MERCURY  VENUS  EARTH  MARS

51 Peg

0.6 M Jup

70 Vir

8.1 M Jup

47 UMa

3.5 M Jup

ORBITAL SEMI-MAJOR AXIS (AU)
Planet parking

- Gas giants form in outer disk and migrate inwards
- Halted at inner edge of accretion disk - determined by stellar magnetic field

Picture: PhilArmitage

- Stellar magnetic field also permeates disk
- Star-disk interaction influences angular momentum evolution
Discovery space for extrasolar planets

Lower limit on mass (Jupiter masses)

Separation (Earth-Sun distance)

Current Detection Limit

HD 209458

Jupiter
Saturn
The sky at about 9:00 p.m. local time in early December, facing toward the west.
An Extrasolar Planet Atmosphere

- HST observations with STIS followed four transits (Brown et al. 2001).
Extrasolar Planets

1 2 3

Star

Planet

Brightness

Time

© Hans Deeg
Extrasolar Planets

Orbital Period: 3.5247 days
Semi-major axis: 0.0468 AU
Mass: $> 0.69 \text{Mass}_{\text{Jup}}$

HD 209458 Light Curve
System Parameters

- The HST transit observations yielded:

  Orbital inclination:
  \[i = 86^{\circ}.6 \pm 0^{\circ}.14\]

  Planet radius:
  \[R_p = 1.347 \pm 0.060 R_J\]

  Stellar radius:
  \[R_* = 1.146 \pm 0.050 R_\odot\]
HST detects additional sodium absorption due to light passing through planetary atmosphere as planet transits across star.

- Additional absorption due to planetary atmosphere.
- Normal absorption spike depth from star.

Sun-like star with its sun in 3.5 Earth days (orbit not to scale).
- Gas-giant planet orbits.
- Brightness of star.
- Duration of transit.
- Light absorbed by planet itself.
- Additional light absorbed by planetary atmosphere.

Time.
Starlight filters through sodium-rich planetary atmosphere

Sodium absorption in star's spectrum is enhanced by sodium in planet's atmosphere
Life in the Galaxy

• **Drake Equation**

\[ N_{\text{civ}} = N_* \times f_p \times f_e \times f_l \times f_c \times f_{\text{lifetime}} \]

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<th>Lib</th>
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<tbody>
<tr>
<td><strong>(N_*)</strong> Solar-type stars in galaxy</td>
<td>(10^{11})</td>
<td>(10^{11})</td>
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<tr>
<td><strong>(f_p)</strong> Fraction of stars which have planets</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>(f_e)</strong> Fraction that are earth-like (suitable for life)</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>(f_l)</strong> Fraction on which life actually arises</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>(f_c)</strong> Fraction that can and choose to communicate</td>
<td>(10^{11})</td>
<td>(10^4)</td>
</tr>
<tr>
<td><strong>(f_{\text{life}})</strong> Survival time of civilization/age of galaxy</td>
<td>(10^{-8})</td>
<td>(10^{-8})</td>
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<tr>
<td>100 yr/(10^{11}) yr</td>
<td>1000</td>
<td>(10^{-4})</td>
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**If 1000 civilizations, on average 100 ly apart**