How to Find Brown Dwarfs and Extrasolar Planets?

PHY 688, Lecture 2
Stanimir Metchev
Previously in PHY 688...
Brown Dwarfs: 
Link between Stars and Giant Planets

- no H fusion
- \( <0.08 \, M_\odot \sim 80 \, M_{\text{Jup}} \)
- star-like properties: 
  - formation, self-luminous, B fields, multiplicity
- planet-like properties: 
  - low \( T_{\text{eff}} \), mass, clouds and “weather”, radius

\[ M \]
\[ 13 \, M_{\text{Jup}} \]
\[ 10 \, M_{\text{Jup}} \]
\[ 5 \, M_{\text{Jup}} \]
\[ 1 \, M_{\text{Jup}} \]

\[ \log_{10} \text{(Age)} \, (\text{Gyrs}) \]

\[ T_{\text{eff}} \, (\text{K}) \]

\[ \text{giant planet formation} \]

\[ \text{stars brown dwarfs “planets”} \]

\[ \text{Burrows et al. (2001)} \]
The Stellar/Substellar Continuum

Sun

(G dwarf)  M dwarf  L dwarf  T dwarf  Jupiter

5700 K  ~3500 K  ~2000 K  ~1000 K  160 K

stars  brown dwarfs  planets

visible light

R. Hurt (Caltech/IPAC)
Hertzsprung-Russel Diagram
1963–1995: The Search for Substellar Objects

- 1985: the disappearing companion vB 8″B"
  - speckle interferometry

- 1988: the unusually cool GD 165B
  - resolved imaging

- 1989: HD 114762b, the first r.v. brown dwarf / planet?
  - radial velocity

\[ \text{2MASS} \]
\( \text{1.2, 1.6, 2.2 \, \mu m} \)
\( \text{color composite} \)

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{HD114762.png}
\caption{HD114762}
\end{figure}

\[ \text{J} \quad \text{H} \quad \text{K} \]

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{Zuckerman&Becklin1988.png}
\caption{(Zuckerman & Becklin 1988)}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{Lathametal1989.png}
\caption{(Latham et al. 1989)}
\end{figure}
1987: G 29–38B?

- primary is a white dwarf
- suspicious infrared excess
  - unresolved brown dwarf companion?
  - dust shell?
- expect periodic modulation of white dwarf pulsation from companion
  - not seen, so dust
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1992: Pulsar Planets!


- pulsar rot. period (~0.006 s) known to $10^{-14}$ s accuracy

- PSR 1257+12bc
  - $\sim 4 \, M_{\text{Earth}}$
  - planets a+d reported later
  - 0.020, 0.0004 $M_{\text{Earth}}$
1992: Pulsar Planets!

- Woloszczan & Frail (1992, Nature)

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  - ~ $4 \, M_{\text{Earth}}$
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  - 0.020, 0.0004 $M_{\text{Earth}}$
1995: Teide 1

- Rebolo et al. (1995, Nature)
- spectroscopic signature of **lithium** in absorption
  - destroyed in the convective interiors of low-mass stars
- candidate member of 100 Myr-old Pleiades open cluster
- but skepticism about age
1995: Gliese 229B!

- Nakajima et al. (1995, Nature)
- Gl 229A is a nearby low-mass M star
- unambiguously cool and substellar
- direct imaging + adaptive optics
  - contrast enhancement
Gl 229B: More Like a Planet Than a Star

Geballe et al. (1996)

[Graph showing emissions of H₂O and CH₄ from Gliese 229B and Titan.]
1995: 51 Pegb!

- first planet detected around a normal star
  – Mayor & Queloz (1995, Nature)
- $M \sin i = 0.47 \, M_{\text{Jup}}$
- primary is a sun-like G2 V star
1995: Substellar Astrophysics Begins
1996–Present:
100’s of Brown Dwarfs and Planets

- brown dwarfs found mostly in large-area sky surveys
  - 0.8–2.5µm
  - DENIS, 2MASS, SDSS

- planets found mostly through radial velocity monitoring of stars

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PHY 688, Lecture 2
## Summary of Substellar Object Detection Techniques

### brown dwarfs
- precision radial velocity monitoring
  - periodic Doppler shift of host star spectrum due to planet’s gravitational pull
- resolved imaging of binary systems
  - seeing-limited, speckle interferometry, adaptive optics
- unresolved photometry of hot stars
  - e.g., cool infrared excess in an otherwise much hotter white dwarf
- large-area sky surveys
  - extremely red objects

### exoplanets
- precision radial velocity monitoring
- pulsar timing
  - apparent periodicity in pulsar rotation period due to planet’s gravitational pull
- transit photometry
  - ~1% dimming of star due to planet passing in front
- microlensing
  - gravitational lensing of light from background stars
- resolved imaging!
  - extremely high-contrast adaptive optics
First Brown Dwarfs Discovered as Companions to Stars

HD 114762b: first brown dwarf?

Gl 229 B: first T dwarf

GD 165 B: first L dwarf

Latham et al. (1987); Becklin & Zuckerman (1988); Nakajima et al. (1995)
...But Most L’s and T’s Now Found from Large-Area Imaging Surveys
# Brown Dwarfs by the Numbers

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.07</td>
<td>Mass of a brown dwarf in solar masses</td>
</tr>
<tr>
<td>&lt; 75</td>
<td>Mass of a brown dwarf in Jupiter masses</td>
</tr>
<tr>
<td>0.1</td>
<td>Radius of an evolved brown dwarf in solar radii</td>
</tr>
<tr>
<td>1</td>
<td>Radius of an evolved brown dwarf in Jupiter radii</td>
</tr>
<tr>
<td>10^{-6}</td>
<td>Lowest measured brown dwarf luminosity (solar units)</td>
</tr>
<tr>
<td>600</td>
<td>Lowest surface temperature of a brown dwarf in °K</td>
</tr>
<tr>
<td>10^{11}</td>
<td>Pressure at the center of a brown dwarf in bar</td>
</tr>
<tr>
<td>3</td>
<td>Number of “spectral classes” of brown dwarfs</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>Number of brown dwarfs known today</td>
</tr>
<tr>
<td>&lt; 1:1</td>
<td>Ratio of brown dwarfs to stars in Galaxy</td>
</tr>
<tr>
<td>&lt; 2</td>
<td>Percentage of dark matter</td>
</tr>
</tbody>
</table>