Alkali Line Profiles in Degenerate Dwarfs

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Ultracool Dwarfs

Kirkpatrick 2005
Ultracool Dwarfs

- Extremely reddened optical/near-IR spectrum of late L and T dwarfs ➔ dust or other opacity source?
(Sub-)stellar atmosphere modelling

- **independent Variables** (minimal):
  - effekte temperature \( T_{\text{eff}} \)
  - surface gravity \( g(r) = GM/r^2 \)
  - mass \( M \) or radius \( R \) or luminosity \( L = 4 \pi R^2 \sigma T_{\text{eff}}^4 \)
(Sub-)stellar atmosphere modelling

- Radiative transfer solution provides thermal structure to determine
- Gas phase physics (ionisation/occupation ratios)
- Chemistry (partial pressures, condensation)
• Dust clouds need to be sustained by turbulent mixing.
• Visible clouds have to be supported by convective overshoot.
• Cloud layer recedes from the photosphere in T dwarfs.
• Atomic and molecular lines becoming more important.
Brown Dwarfs — Line Absorption

- Most atoms in ground state, little contribution at longer wavelengths
- Spectral energy distribution shifts toward IR
- Importance of molecular bands dependent on:
  - Line strengths $\leftrightarrow gf$, abundances, chemistry
  - Line shapes
  - Line numbers
  - Line distribution
- Bands with complex spectra (polyatomic molecules) produce strongest blanketing effects.
Ultracool Atmosphere Models

- Coming and going of dust clouds explains the M-L-T spectra (Allard et al. 2001)
- Molecules: 3500-2500 K
- Dust: 2500-1500 K
- CH4: 1500-500 K
T Dwarfs — Dust-free atmospheres

- No visible dust → Massive alkali line broadening responsible for optical/near-IR absorption
T Dwarfs — Alkali lines

- Depletion of metals due to condensation and sedimentation
- Alkali resonance lines still strong in deep atmosphere layers
- Powerful probe of atmosphere at very different optical depths!

![Graph showing the distribution of Na, K, Rb, Cs, CrH, and FeH in T Dwarfs.](image)
Impact and single-perturber approximations with accurate inter-atomic potentials (Allard et al. 2005, 2007)
T Dwarfs - Alkali lines

- Broadening by He and H$_2$ (several geometries)
- Far wings shape spectrum over several $\mu$m!

Profiles from Allard, Allard, Hauschildt, Kielkopf & Machin (2003, 2007)
A Unified Set of Model Atmospheres

M-L-T-(Y?)-dwarfs

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Alkali Lines in Degenerate Dwarfs
Interaction potentials show local minimum

→ quasi-molecular resonance in the blue wing
Absorption in the blue wing of K\textsc{I}

- CaH “resurgence” - a molecular band returning or a new absorption feature?
Alkali lines - quasi-molecular satellites!

- New profiles by Allard, Spiegelmann & Kielkopf 2007
Challenges - Alkali chemistry

- Depletion of refractory species depends on complex chemical reaction network and mixing properties
Challenges - Alkali chemistry

• Modelling of condensation still important in late T dwarfs!
• Gas density in line-forming region exceeds $10^{20}$ cm$^{-3}$
  $\rightarrow$ single-perturber approximation no longer valid in wings
Alkali lines in White Dwarfs

- Strong $V$ absorption in metal-rich cool white dwarfs
- Evidence for extremely pressure-broadened Na lines

Oppenheimer et al. 2001, Salim et al. 2004 (obs.)
Homeier et al. EuroWD 06

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Alkali Lines in Degenerate Dwarfs

VIth SCSLSA 12 June 2007
Alkali lines in White Dwarfs

H-models log $g$ = 8.0, [M/H]=-3.5, [Na,K/H]=-1.5

- 2 ultra-cool white dwarfs with strong Na absorption
- Hydrogen- or Helium-dominated atmosphere?

Harris et al. 2003 (obs.)
Homeier et al.
EuroWD 06

Derek Homeier  Alkali Lines in Degenerate Dwarfs
FT Expansion breaks down at high density

- Standard density expansion to $3^{rd}$ or even $7^{th}$ order only carries a fraction of the line strength!
FT Expansion breaks down at high density

- Better treatment of far wings by direct calculation required for densest objects!
Conclusions

• Atmosphere models have made great progress towards understanding substellar objects

• Condensation and depletion of dust species explains the properties of L dwarfs and the transition from L to T

• Line absorption paramount to correctly model T dwarfs

• Few, massively broadened alkali resonance lines shape large regions of brown dwarf spectra

• Next generation of line profiles needed to model atmospheres of still denser objects → Y dwarfs, metal-rich white dwarfs

Thanks for your attention &
Thanks to the organisers!

Derek Homeier                                      Alkali Lines in Degenerate Dwarfs                                                                                                                                  VI
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