White dwarfs, brown dwarfs and debris disks with UKIDSS

with Paul Steele (now MPE Garching), Jay Farihi, Richard Jameson, Sarah Casewell, Paul Dobbie (transported to Tasmania)

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Motivation

- Investigate the known deficit of BD companions to main sequence stars
- WD gives an age constraint: benchmark BDs for testing evolutionary and atmospheric models
  - Pinfield et al. (2006)
- In close systems, irradiated BD provides a laboratory for testing models of heated substellar atmospheres (hot Jupiters)
  - WD0137-349
- Post-CE systems may provide another channel for CV evolution
  - What is the lowest mass object that can survive a CE?
  - What fraction of CVs are born with a BD secondary?
  - Growing number of CVs with confirmed BD secondaries
    - Including examples thought to have formed directly from a detached WD +BD progenitor, e.g. SDSS J150722.30+523039.8, Littlefair et al. (2007)
Known detached WD+BD binaries

- Historical searches for brown dwarf companions to WDs going back to 1980s

- Rare: only three confirmed systems prior to UKIDSS
- GD165
  - 120AU separation, L4 secondary
  - Becklin & Zuckerman (1988)
- GD1400
  - L6/7 secondary
  - Farihi & Christopher (2004), Dobbie et al. (2005)
- WD0137-349
  - P=116 mins, L8 secondary (0.053Msun)
  - Maxted et al. (2006); Burleigh et al. (2006)

- Previous estimate of fraction of L dwarf companions <0.5%
  - (Farihi et al. 2005, survey of >300 WDs)
  - Only GD165 a firm detection in 2MASS
Searching for unresolved WD+BD binaries in UKIDSS

- Cross-correlate UKIDSS LAS releases with
  - SDSS DR4 spectroscopically id-ed WDs (Eisenstein et al. 2006)
  - McCook and Sion WDs
  - Total ~1000 WDs T>7-8000K
- J-H v H-K plot provides an initial selection
- Better method: model each WD SED, with model atmospheres
  - Identify WDs with >3 sigma excesses at H and K
IR searches for substellar companions: UKIDSS survey results

- ~dozen new BD candidates
- Several now confirmed
- WD+L fraction >0.4+/-0.3%
- WD+T fraction >0.2%
- WD+BD fraction >0.5+/-0.3%
- Caveat: Only 16% of sample sensitive to mid T dwarfs & only 4% of sample sensitive to T8
- See also similar study by Girven et al. 2011, MNRAS, 417, 1210
- Parallel study for very wide binaries in UKIDSS discovered a WD+T4.5 (Day-Jones et al. 2009)
- Within errors, BD companion fraction agrees with main sequence + BD estimates
Follow-up: PHL5038

- $B=18$, UKIDSS $K=16.7$
- Follow-up imaging and spectroscopy with Gemini-North + NIRI
- Resolved at 0.92" (=55AU projected)
- L8 companion ($T\sim 1600K$, $M\sim 0.055M_{\text{sun}}$)
- WD $T=8000\pm 100K$, $M=0.72\pm 0.15M_{\text{sun}}$, $d=64\pm 10$pc
  - Total age 1.9-2.7Gyr
- 4th known WD+BD detached system, 2nd wide
  - Benchmark at L-T transition
Follow-up: a close binary

- WD + L5 brown dwarf
- Secondary mass 54-56M$_{Jup}$
- Shortest period spectroscopically identified WD+BD binary: 102 mins
- Distance 60±10 pc.
- Likely to have survived a stage of common envelope evolution like its counterpart WD0137-349
- Steele et al. 2012 in prep
Dust disks around white dwarfs

- Around 20 WDs are now known to be surrounded by dust disks
  - Most found since 2005 through Spitzer and UKIRT/UKIDSS
- Disks identified as near-IR and mid-IR excesses, $500^\circ K < T < 1500^\circ K$
- Disks within a few solar radii of the WDs
- Material within the disks is being accreted onto the WD atmosphere
  - Abundances reminiscent of solar system chondrites, Moon, Earth....
- Disks dominated by silicates
- Disk forms from tidal disruption terrestrial body
  - Mass of GD362 disk suggests Mars-sized body
Dust disks in UKIDSS

- UKIDSS has done an unbiased survey for dust disks around white dwarfs >8000K
- Several new examples found
- Fraction of H-rich DA white dwarfs with disks >0.8%
- No disks found around WDs >25,000K
- All the white dwarfs with disks are metal polluted
- If consider all metal polluted WDs have accreted terrestrial material
  - >20% of WDs have rocky planets / asteroids
Summary

- UKIDSS has quadrupled the number of known WD + BD binaries (fraction = 0.5+/-0.3%)
  - Proxy for main sequence / brown dwarf binaries
  - Probe brown dwarf “desert” & formation scenarios (cf Sarah Casewell’s talk)
  - Examine extreme of common envelope evolution (& hence CV formation)
  - Study heated substellar atmospheres
- UKIDSS has made an unbiased survey for dust disks
  - ~1% of WDs have disks
  - WDs are telling us that up to ~20% of intermediate mass stars form terrestrial planets / asteroids
Next

• VISTA – measure T dwarf companion fraction
• UHS in K band would be nice for disks....
• Follow-up studies
WDs + BDs: Next stage

• Awarded VLT + x-shooter, Gemini + NIRI and IRTF time for spectroscopy of candidate binaries
• Determine periods and secondary masses for candidate close binaries
  – Optical/IR photometric variability c.f. WD0137-349
  – Radial velocities of brown dwarfs from Halpha emission (WD0137-349) or near-IR spectroscopy
  – Space density of post-CE WD+BD systems
• Further candidates from future UKIDSS data releases
• Exploit VISTA
  – Increase sample size esp. for T dwarfs
• Exploit WISE
  – Increased sensitivity to T dwarfs and possibly cooler
WD0137-349: discovery observations

- Double-lined spectroscopic binary
- H-alpha absorption from WD in black
- Emission from irradiated face of companion in white
- Note anti-phase variability
- Period: 116 minutes
- $M_1 = 0.39 \pm 0.035M_{\odot}$
- $M_2 = 0.053 \pm 0.006M_{\odot}$

Irradiation of WD0137-349B

Green - K (±14%)

Red - H (±8%)

White - J (±3%)

Spitzer IRAC 4.5 microns
GD1400 is also post-CE

- Unresolved in Keck and HST images
- Radial velocity campaign with VLT + UVES
- $P_{\text{orb}} = 0.4158$ days $= 9.98$ hours
- $M_{\text{wd}} = 0.55-0.65M_{\odot}$
  - $M_{\text{bd}} \sin i = 0.06-0.07M_{\odot}$
- System age $> 1$ Gyr
- Burleigh et al. (2010)
GD1400 evolutionary history

- WD has a mass between 0.55-0.65$M_{\text{sun}}$
  - CO-core
- Progenitor mass 2-3$M_{\text{sun}}$
- Post-main sequence RGB evolution proceeded as normal
- Common envelope with BD happened on AGB
  - Radius of 2.5$M_{\text{sun}}$ RGB star = $25R_{\text{sun}}/0.12\text{AU}$
  - Radius of 2.5$M_{\text{sun}}$ AGB star = $250R_{\text{sun}}/1.2\text{AU}$
- Hence BD originally orbited between 0.1-1.2AU
- In contrast, WD0137-349 has $M_{\text{WD}}=0.39M_{\text{sun}}$, and a He-core