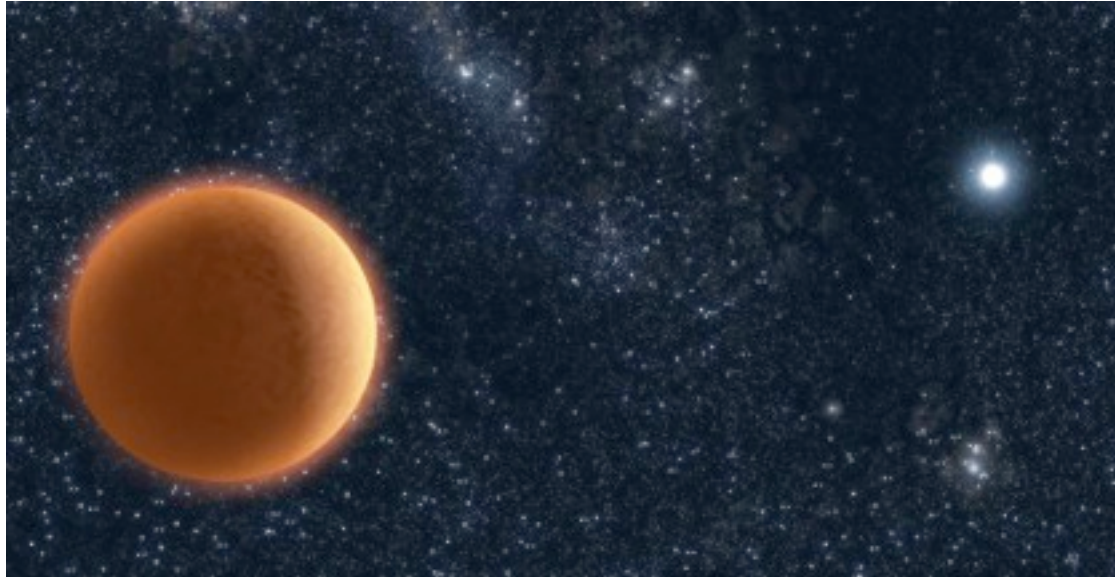


# White dwarfs, brown dwarfs and debris disks with UKIDSS

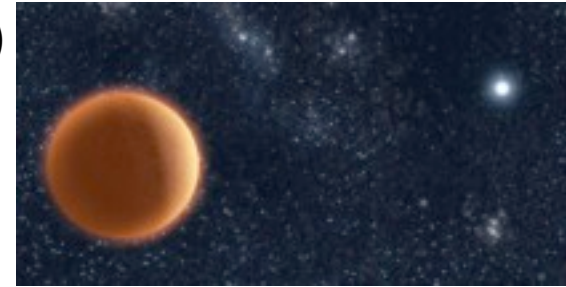


*with Paul Steele (now MPE Garching), Jay Farihi, Richard Jameson, Sarah Casewell,  
Paul Dobbie (transported to Tasmania)*

*Boris Gaensicke and Jonathan Girven (Warwick)*

# Motivation

- Investigate the known deficit of BD companions to main sequence stars
  - McCarthy & Zuckerman (2004), Grether & Lineweaver (2006)
- 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)



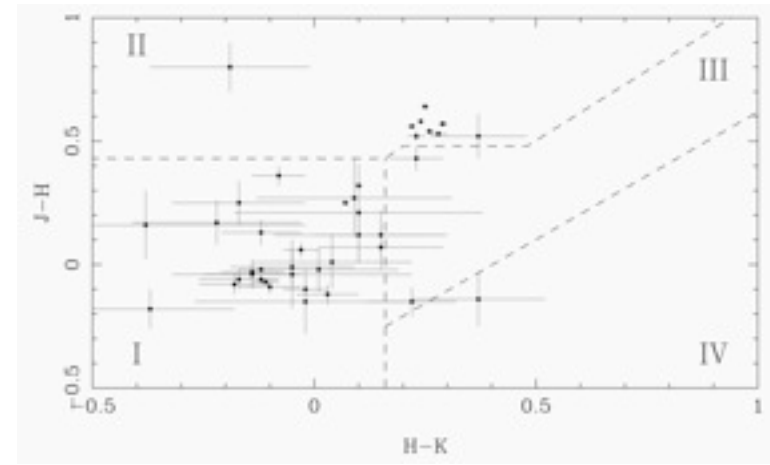
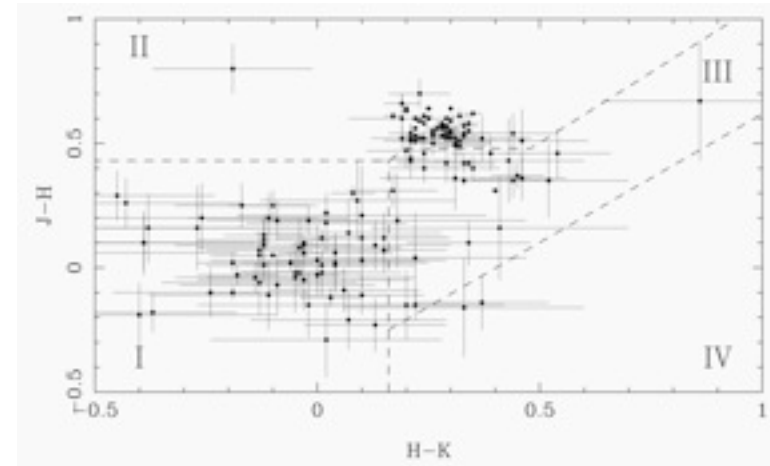
# Known *detached* WD+BD binaries

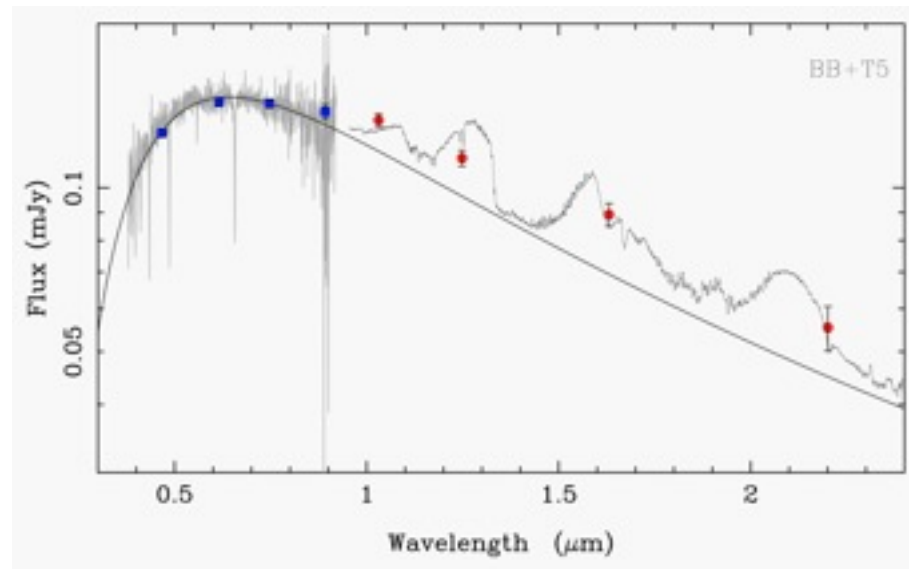
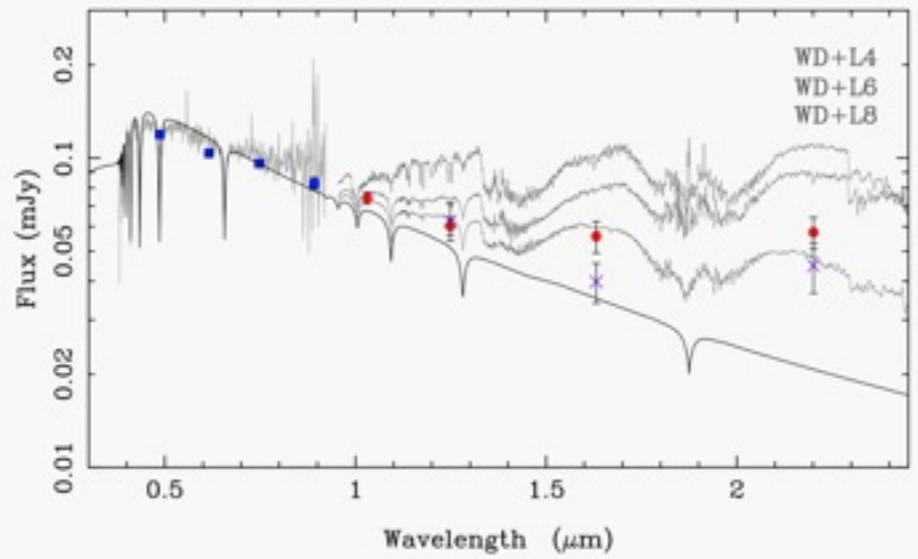
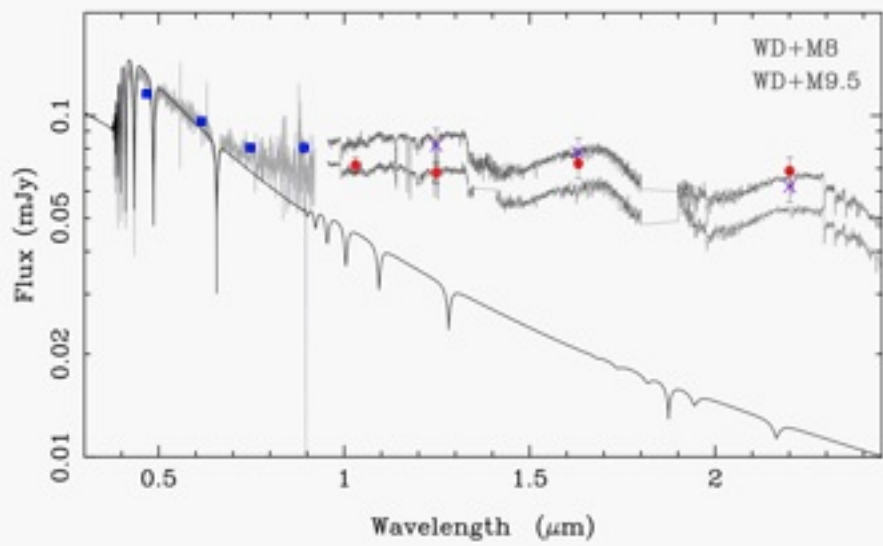
- Historical searches for brown dwarf companions to WDs going back to 1980s
  - eg Probst (1983), Zuckerman & Becklin (1987), Wachter et al. (2003), Farihi et al. (2005), Dobbie et al. (2005), Tremblay & Bergeron (2007)
- Rare: only three confirmed systems prior to UKIDSS
- GD165
  - 120AU separation, 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

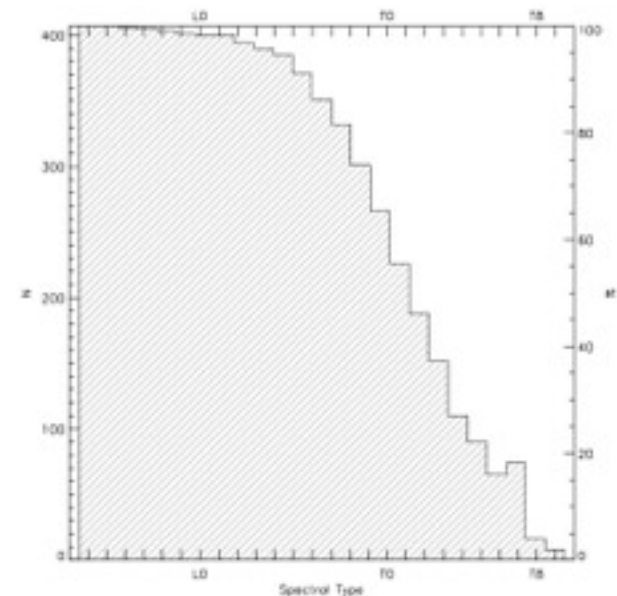
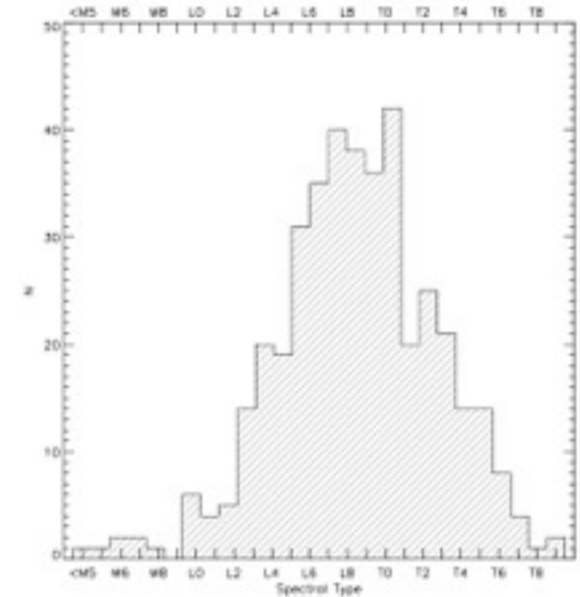
- Cross-correlate UKIDSS LAS releases with
  - SDSS DR4 spectroscopically id-ed WDs (Eisenstein et al. 2006)
  - McCook and Sion WDs
  - Total  $\sim 1000$  WDs  $T > 7-8000\text{K}$
- J-H v H-K plot provides an initial selection
- Better method: model each WD SED, with model atmospheres
  - Identify WDs with  $>3$  sigma excesses at H and K





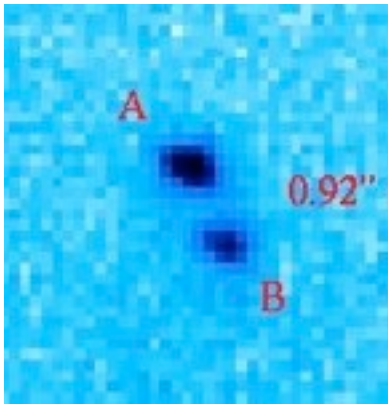
# IR searches for substellar companions: UKIDSS survey results

- ~dozen new BD candidates
- Several now confirmed
- WD+L fraction  $>0.4 \pm 0.3\%$
- WD+T fraction  $>0.2\%$
- WD+BD fraction  $>0.5 \pm 0.3\%$
- Caveat: Only 16% of sample sensitive to mid T dwarfs & only 4% of sample sensitive to T8
- *Steele et al. 2011, MNRAS, 416, 2768*
- 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
  - McCarthy & Zuckerman (2004), Grether & Lineweaver (2006)

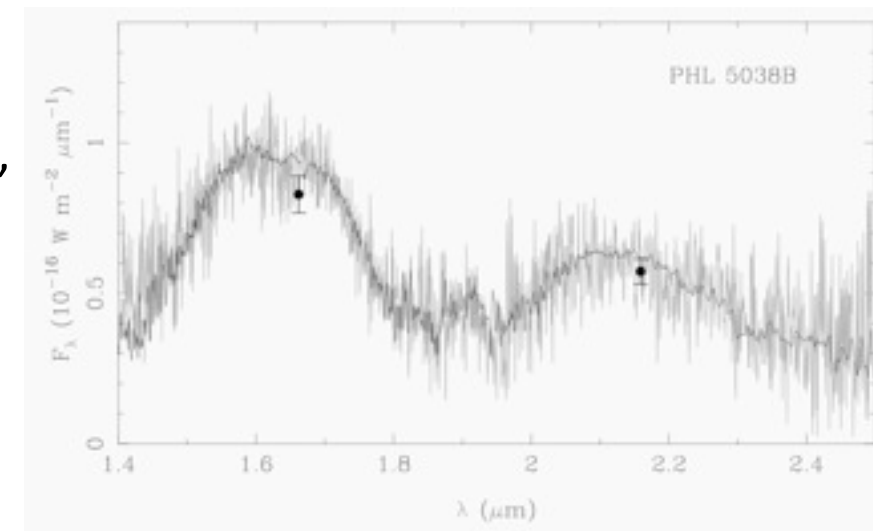
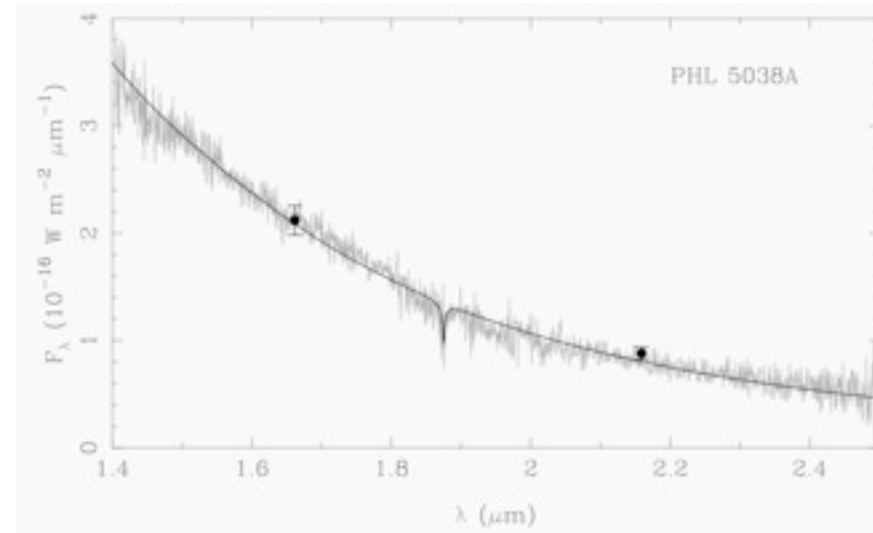


# Follow-up: PHL5038

K

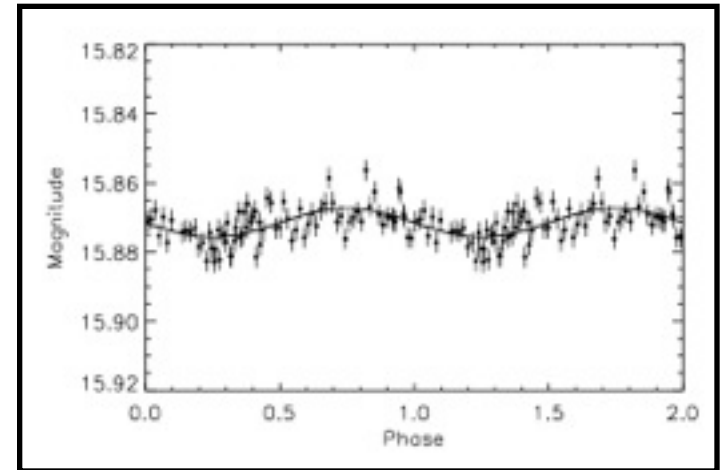
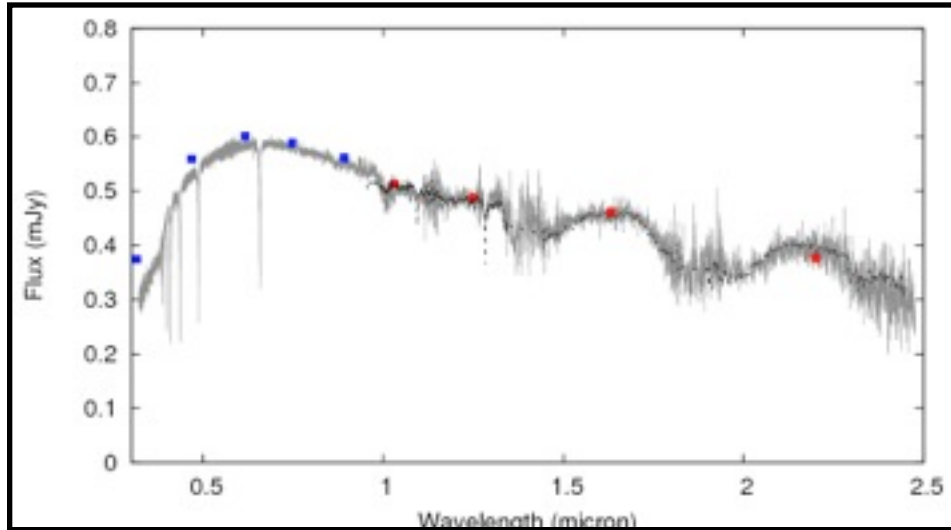


- $B=18$ , UKIDSS  $K=16.7$
- Follow-up imaging and spectroscopy with Gemini-North + NIRI
- Resolved at  $0.92''$  (=55AU projected)
- L8 companion ( $T\sim 1600\text{K}$ ,  $M\sim 0.055M_{\text{sun}}$ )
- WD  $T=8000\pm 100\text{K}$ ,  $M=0.72\pm 0.15M_{\text{sun}}$ ,  $d=64\pm 10\text{pc}$ 
  - Total age 1.9-2.7Gyr
- 4th known WD+BD detached system, 2nd wide
  - *Benchmark at L-T transition*
- *Steele et al. 2009, A&A, 500, 1207*

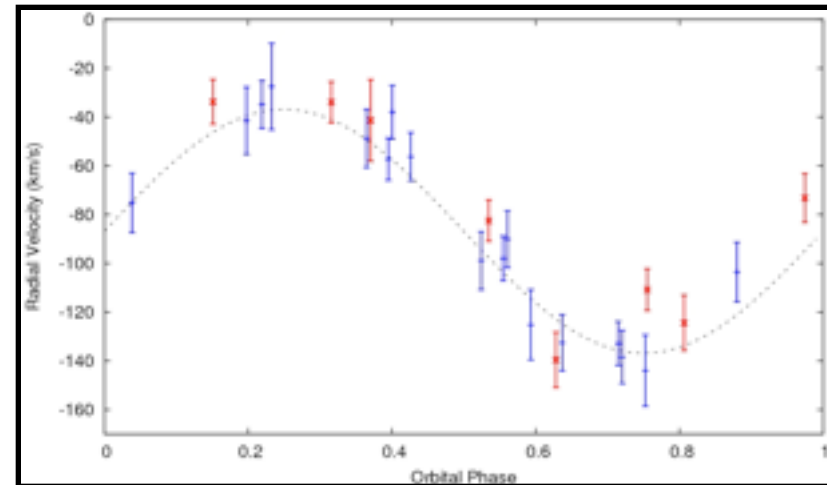




# Follow-up: a close binary

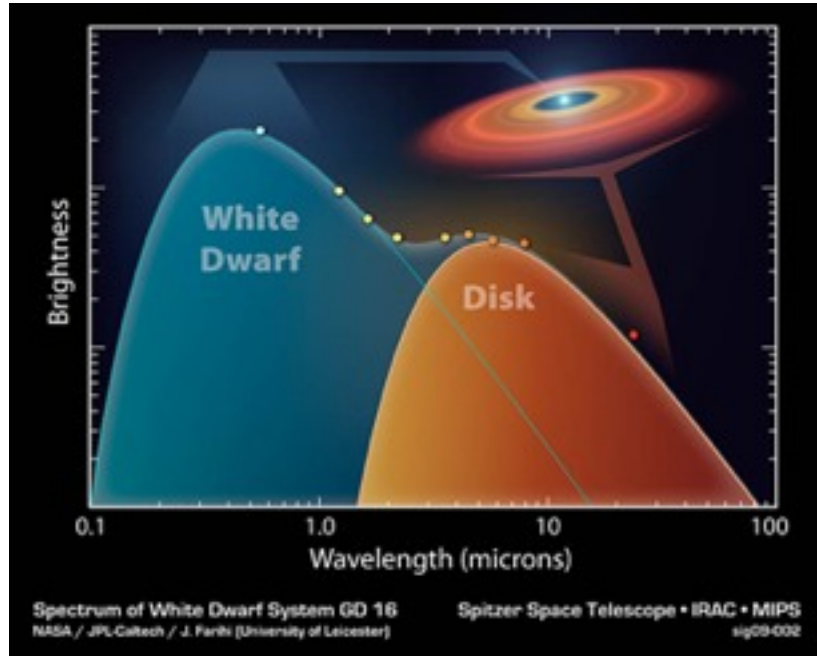


- WD + L5 brown dwarf
- Secondary mass  $54-56M_{\text{Jup}}$
- Shortest period spectroscopically identified WD+BD binary: 102 mins
- Distance  $60 \pm 10$  pc.
- Likely to have survived a stage of common envelope evolution like its counterpart WD0137-349
- *Steele et al. 2012 in prep*





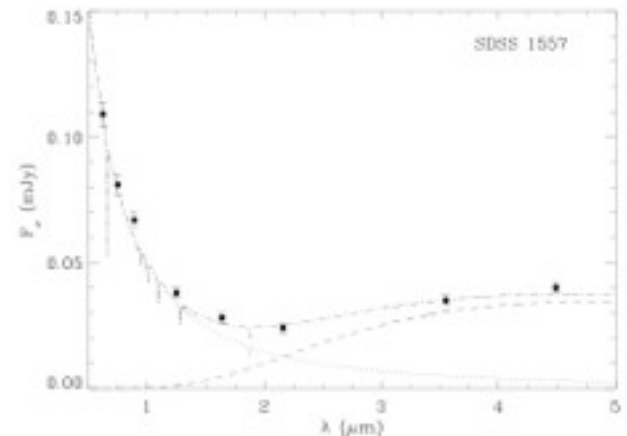
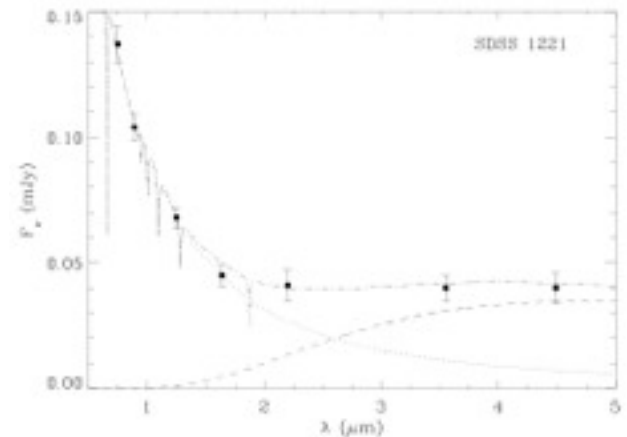
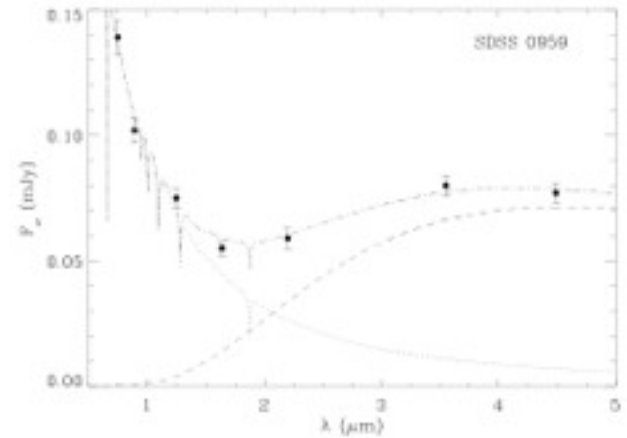
# Dust disks around white dwarfs



- 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,  $500^{\circ}\text{K} < T < 1500^{\circ}\text{K}$
- 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
- *Farihi et al. 2012, MNRAS, 421, 1635*



# Summary

- UKIDSS has quadrupled the number of known WD + BD binaries (fraction =  $0.5\pm 0.3\%$ )
  - 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

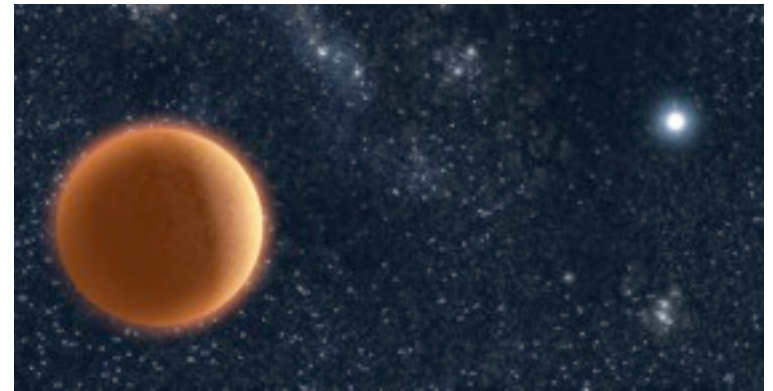
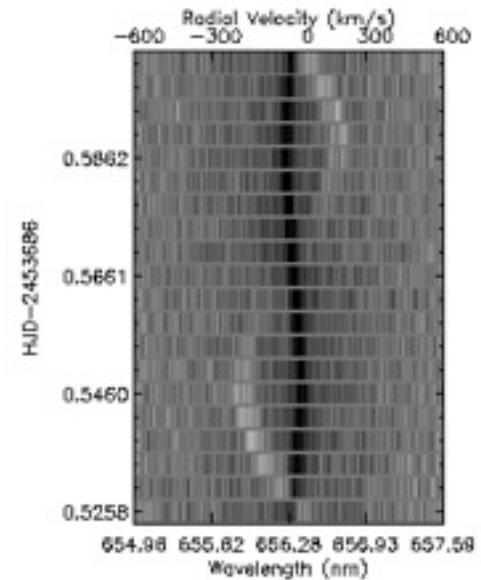
- Awarded VLT + x-shooter, Gemini + NIRI and IRTF time for spectroscopy of candidate binaries
- Determine periods and secondary masses for candidate close binaries
  - Optical/IR photometric variability c.f. WD0137-349
  - Radial velocities of brown dwarfs from H $\alpha$  emission (WD0137-349) or near-IR 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
- $M_1 = 0.39 \pm 0.035 M_{\text{sun}}$
- $M_2 = 0.053 \pm 0.006 M_{\text{sun}}$

– Maxted et al. 2006, *Nature*, 442, 543

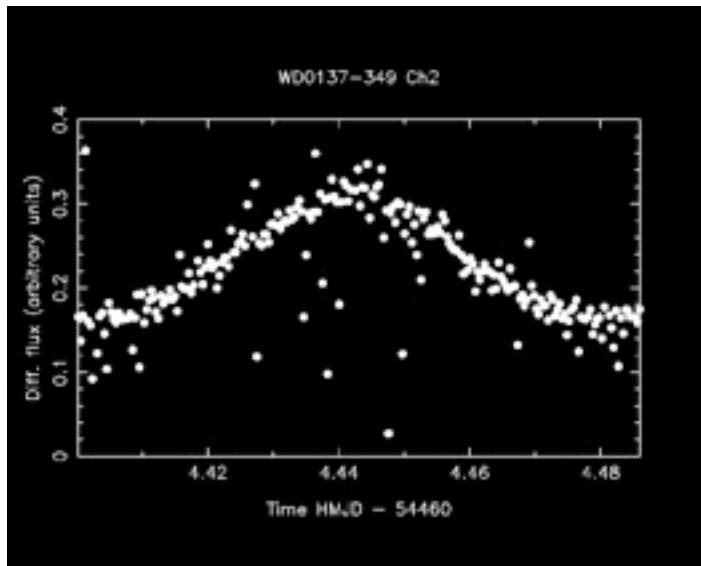
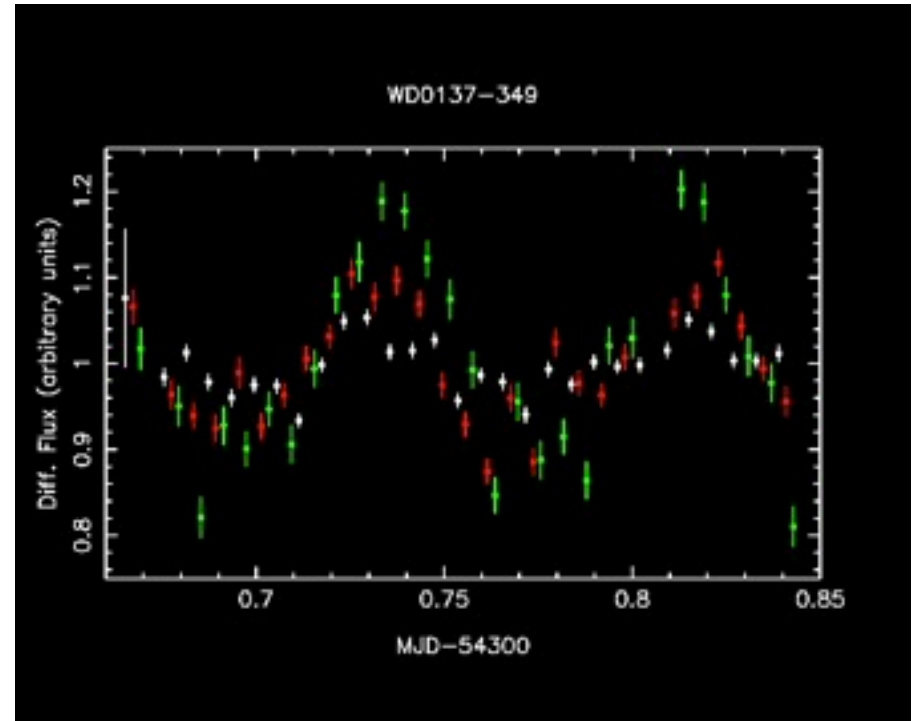


# Irradiation of WD0137-349B

Green - K (+/-14%)

Red - H (+/- 8%)

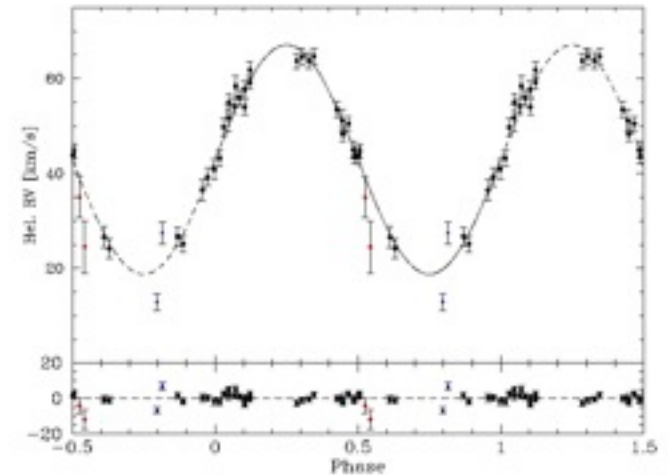
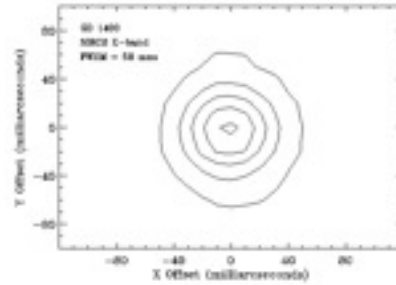
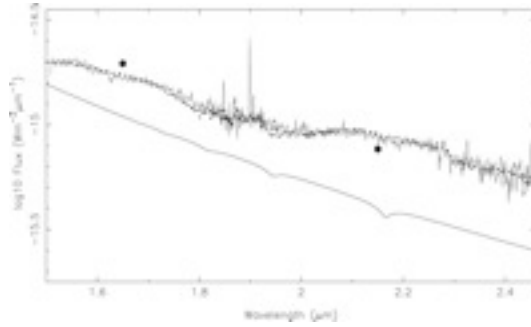
White - J (+/- 3%)



Spitzer IRAC 4.5 microns



# GD1400 is also post-CE



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

# GD1400 evolutionary history

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

