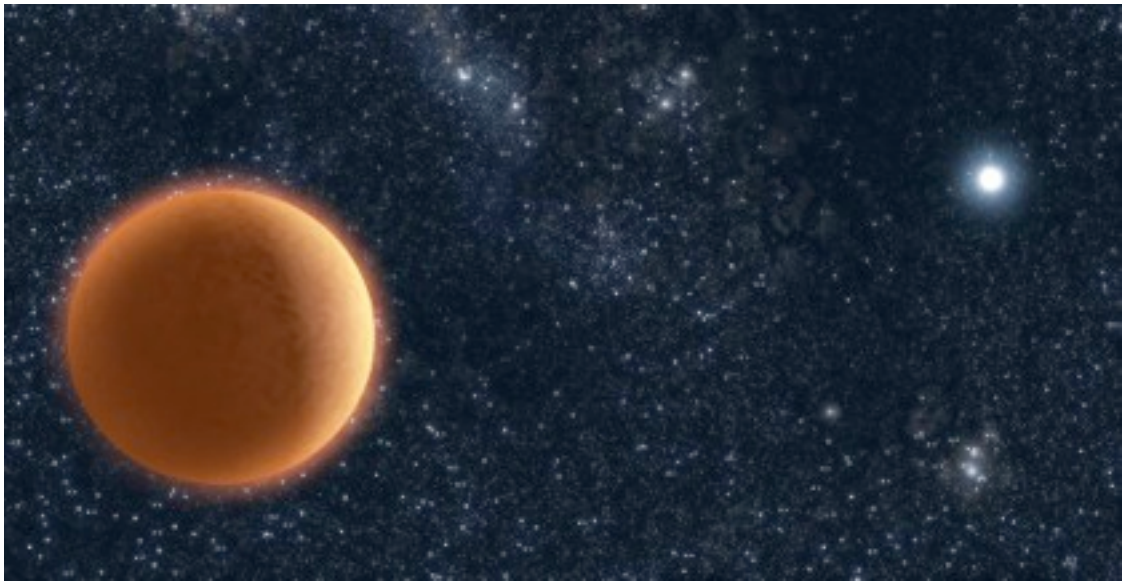
White dwarfs, brown dwarfs and debris disks with UKIDSS

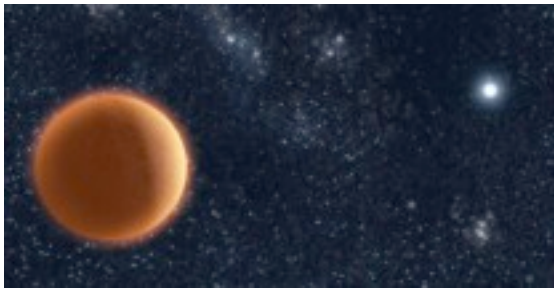


with Paul Steele (now MPE Garching), Jay Farihi, Richard Jameson, Sarah Casewell, Paul Dobbie (transported to Tasmania)

Boris Gaensicke and Jonathan Girven (Warwick)

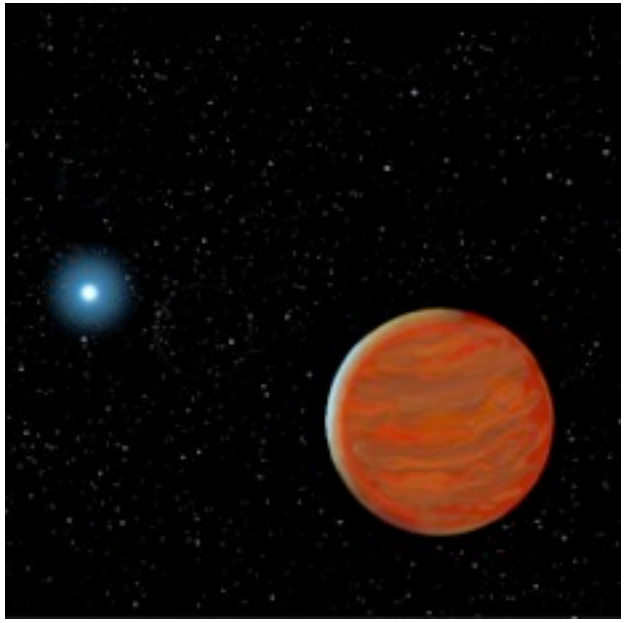
Motivation

- 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)



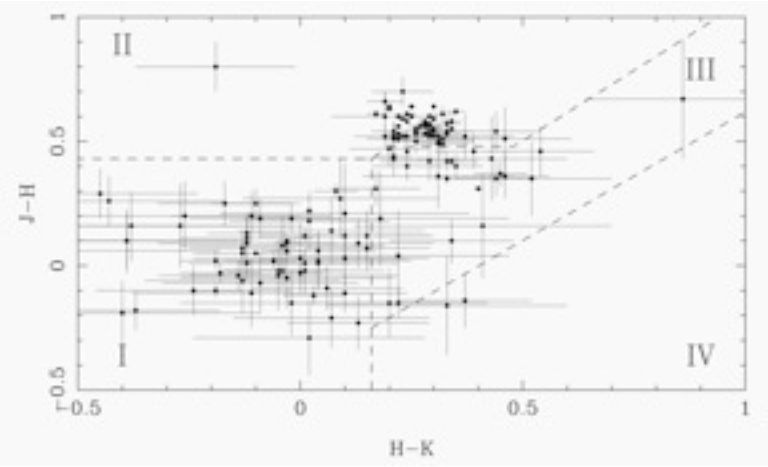
Known *detached* WD+BD binaries

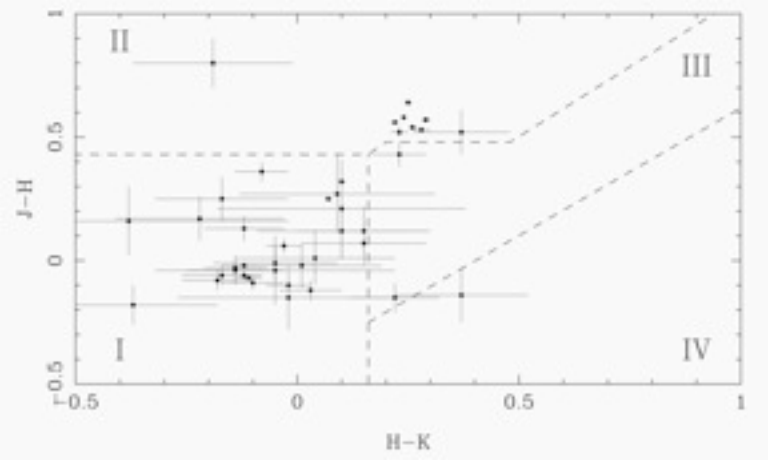
- Historical searches for brown dwarf companions to WDs going back to 1980s
  - eg Probst (1983), Zuckerman & Becklin (1987), Wachter et al. (2003), Farihi et al. (2005), Dobbie et al. (2005), Tremblay & Bergeron (2007)
- Rare: only three confirmed systems prior to UKIDSS
- GD165
  - 120AU separation,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

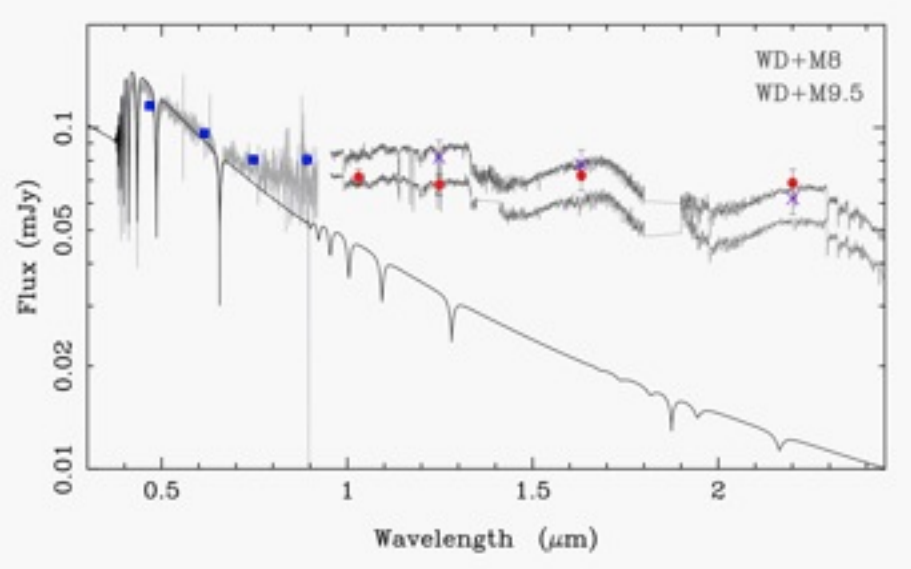


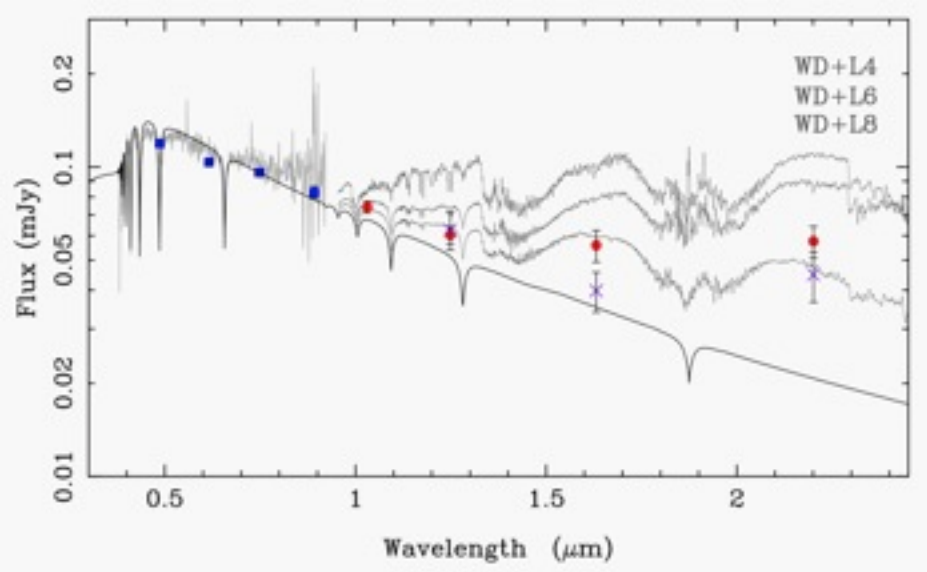
Searching for unresolved WD+BD binaries in UKIDSS

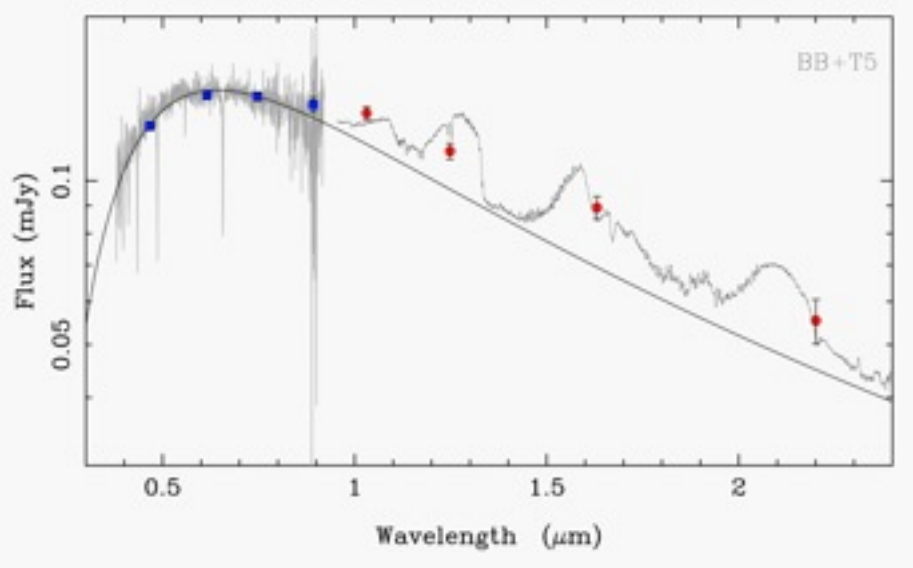
- Cross-correlate UKIDSS LAS releases with
  - SDSS DR4 spectroscopically id-ed WDs (Eisenstein et al. 2006)
  - McCook and Sion WDs
  - Total ~1000 WDs T>7-8000K
- J-H v H-K plot provides an initial selection
- Better method: model each WD SED, with model atmospheres
  - Identify WDs with >3 sigma excesses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





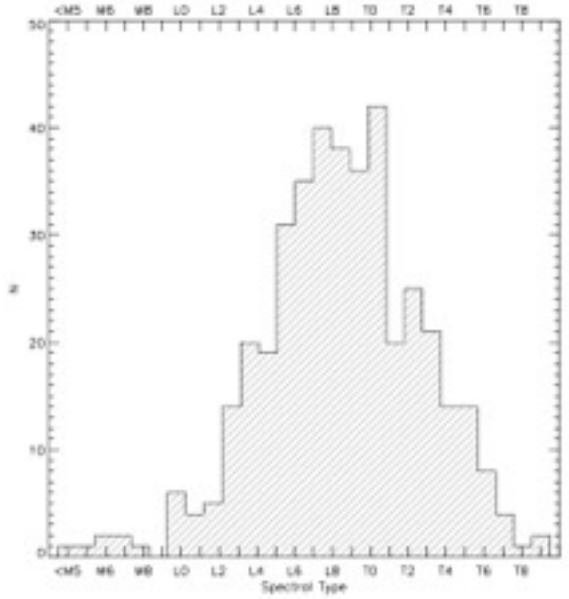

WD+M8
WD+M9.5
Flux (mJy)
0.01
0.02
0.05
0.1
0.5
1
1.5
2
Wavelength (μm)

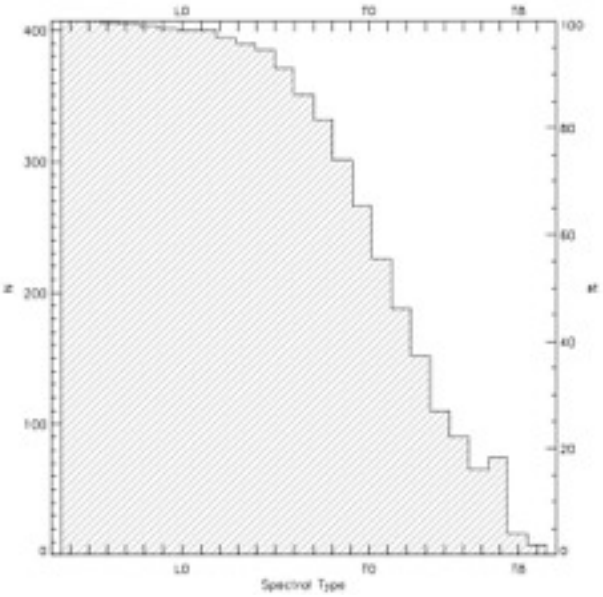

WD+L4
WD+L6
WD+L8
Flux (mJy)
0.01
0.02
0.05
0.1
0.2
0.5
1
1.5
2
Wavelength (μm)


BB+T5
Flux (mJy)
0.05
0.1
0.5
1
1.5
2
Wavelength (μm)

IR searches for substellar companions: UKIDSS survey results

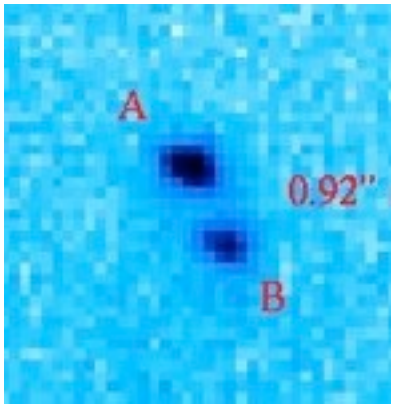
- ~dozen new BD candidates
- Several now confirmed
- WD+L fraction >0.4+/-0.3%
- WD+T fraction >0.2%
- WD+BD fraction >0.5+/-0.3%
- Caveat: Only 16% of sample sensitive to mid T dwarfs & only 4% of sample sensitive to T8
- *Steele et al. 2011, MNRAS, 416, 2768*
- See also similar study by *Girven et 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)

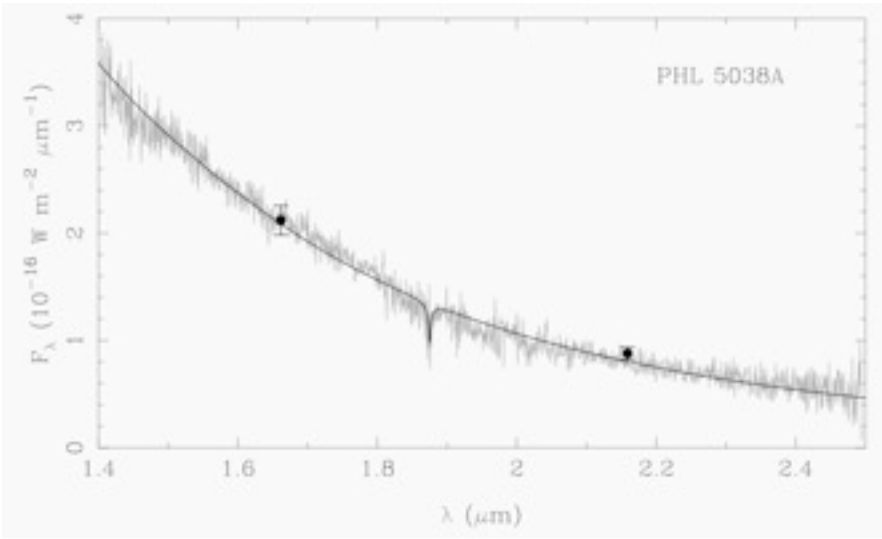


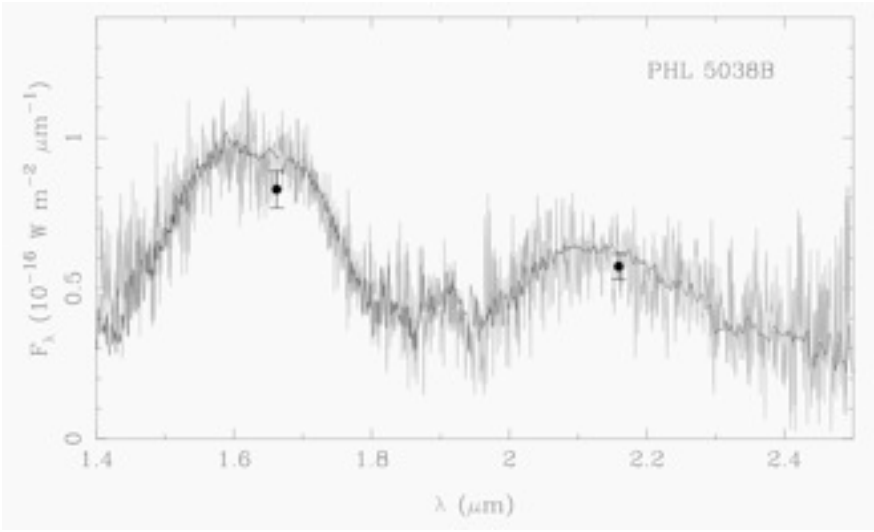


Follow-up: PHL5038

K

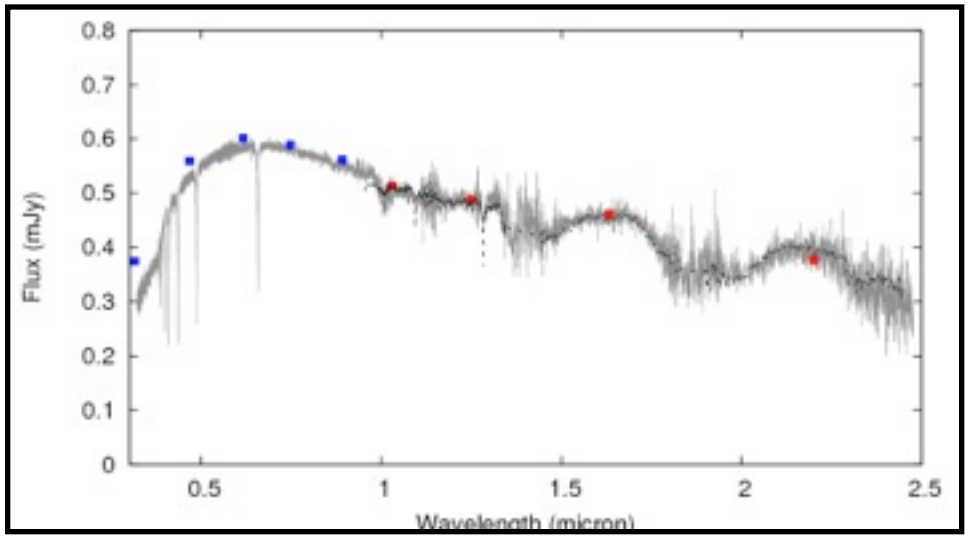


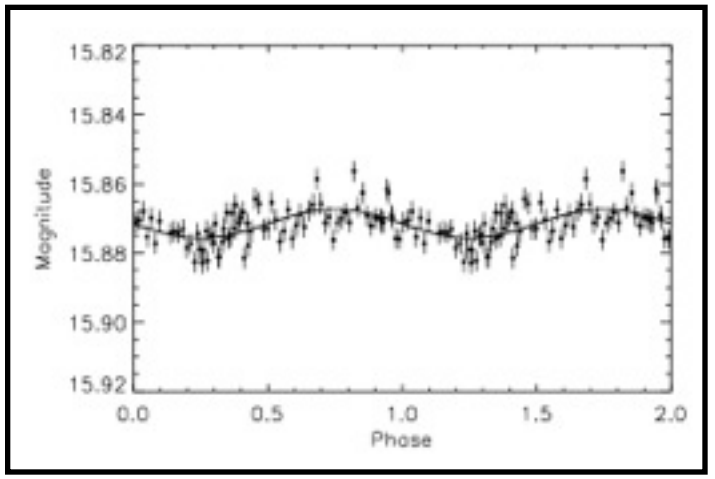




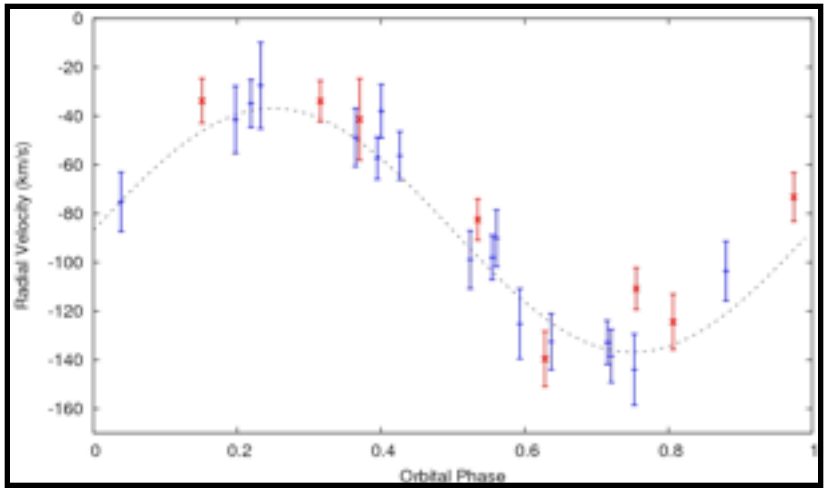
- *B*=18, UKIDSS *K*=16.7
- Follow-up imaging and spectroscopy with Gemini-North + NIRI
- Resolved at 0.92” (=55AU projected)
- L8 companion (T~1600K, M~0.055Msun)
- WD T=8000+/-100K, M=0.72+/-0.15Msun, d=64+/-10pc
  - *Total age 1.9-2.7Gyr*
- 4th known WD+BD detached system, 2nd wide
  - *Benchmark at L-T transition*
- *Steele et al. 2009, A&A, 500, 1207*

Follow-up: a close binary

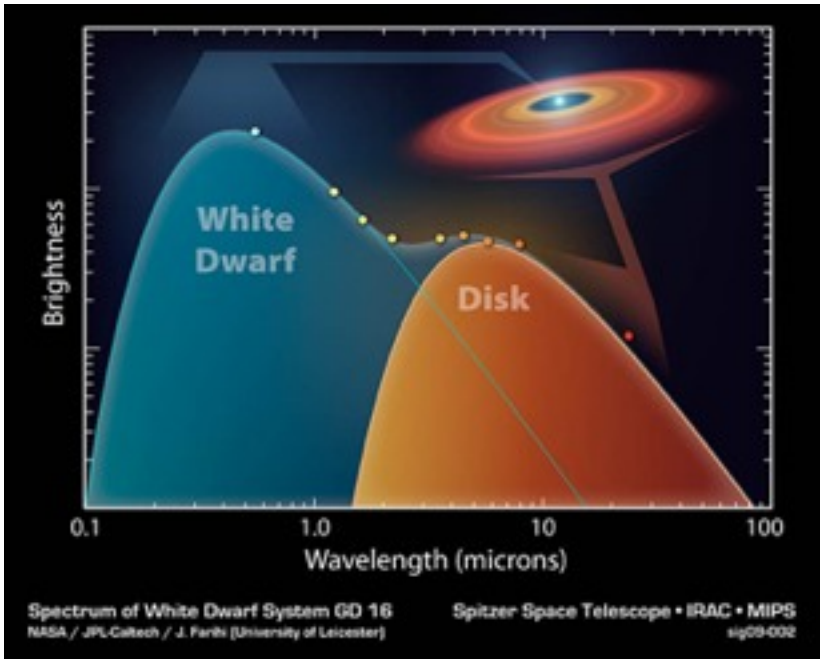




- WD + L5 brown dwarf
- Secondary mass 54-56M_{Jup}
- Shortest period spectroscopically identified WD+BD binary: 102 mins
- Distance 60±10 pc.
- Likely to have survived a stage of common envelope evolution like its counterpart WD0137-349
- *Steele et al. 2012 in prep*



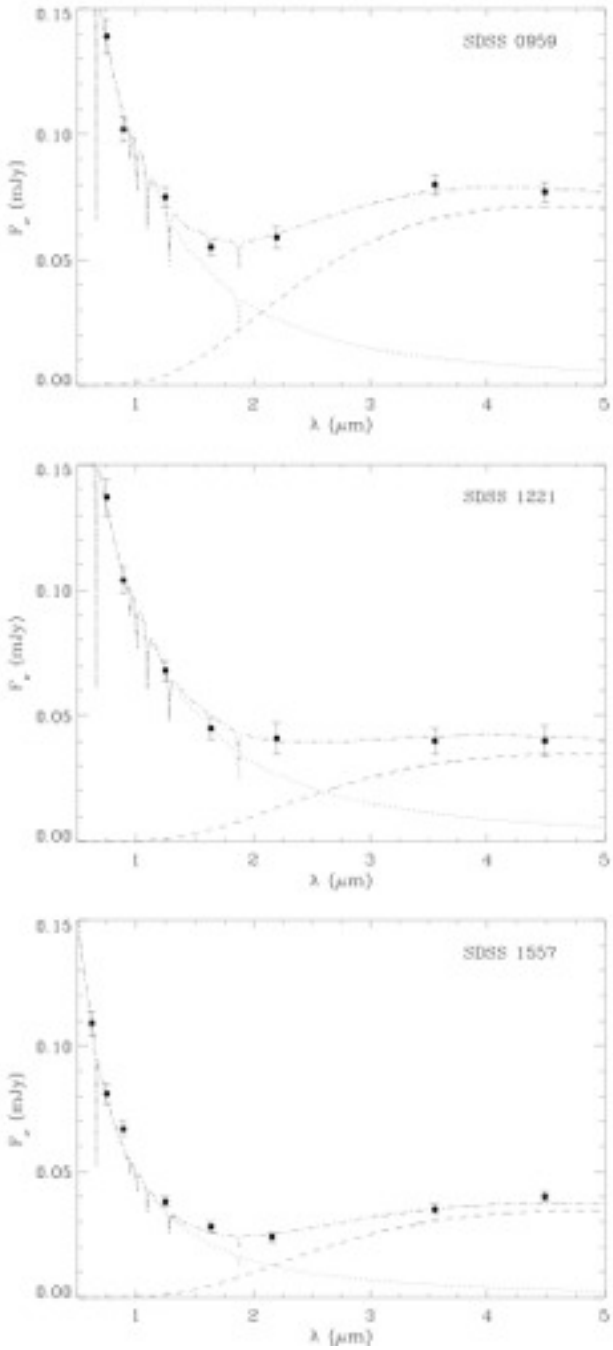
Dust disks around white dwarfs



- 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, $500^{o}K < T < 1500^{o}K$
- 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+/-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

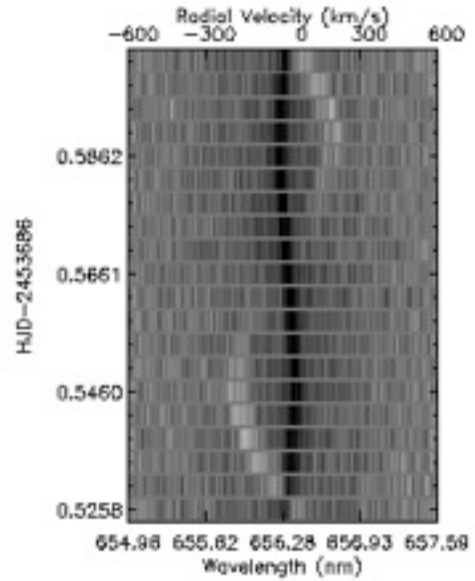
- VISTA – measure T dwarf companion fraction
- UHS in K band would be nice for disks….
- Follow-up studies

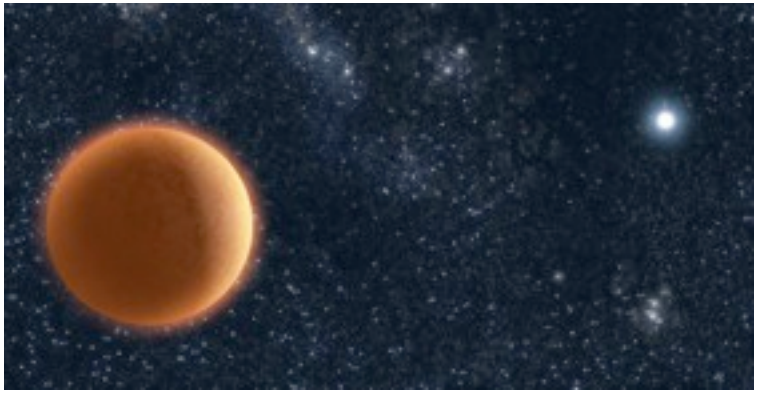
WDs + BDs: Next stage

- 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 +/- 0.035M_{sun}
- M_2 = 0.053 +/- 0.006 M_{sun}
  - Maxted et al. 2006, Nature, 442, 543



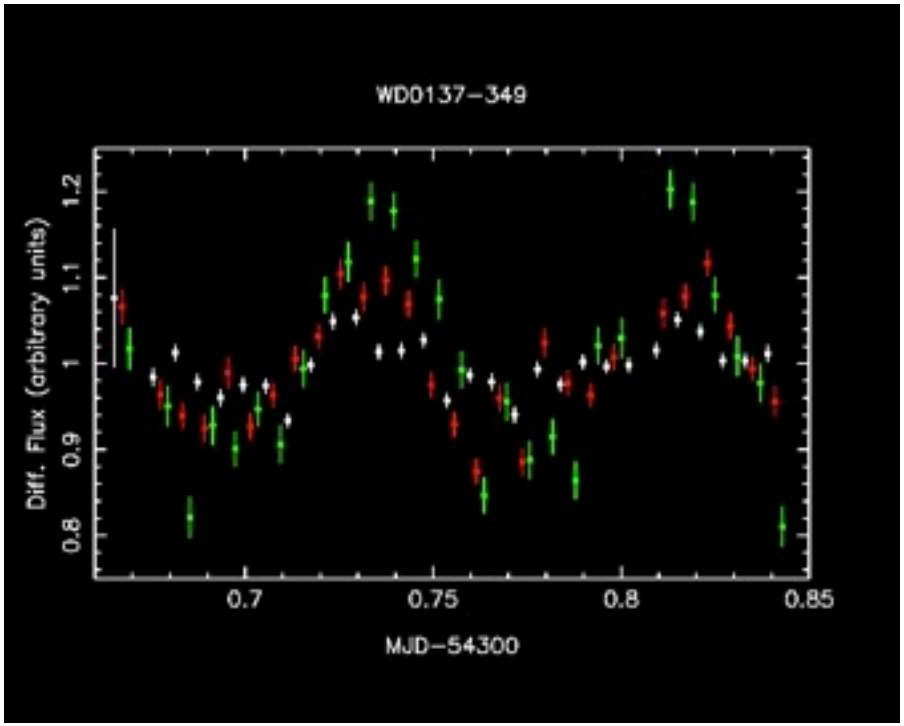


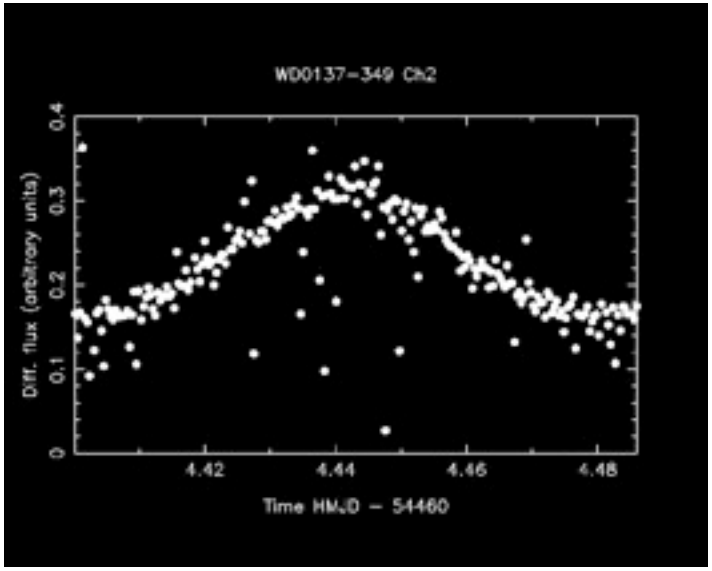
Irradiation of WD0137-349B

Green - K (+/-14%)

Red - H (+/- 8%)

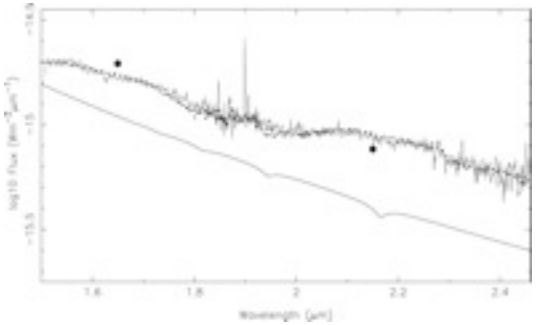
White - J (+/- 3%)

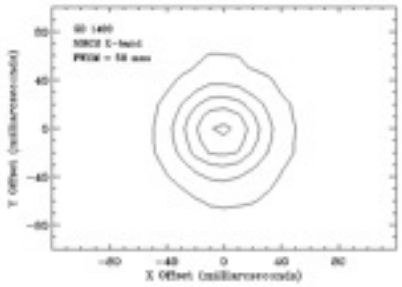


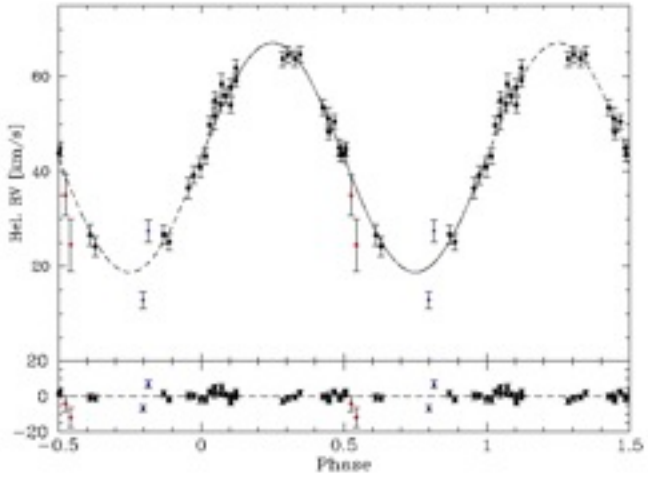


Spitzer IRAC 4.5 microns

GD1400 is also post-CE







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

GD1400 evolutionary history

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