The DODO Survey: Imaging Planets Around White Dwarfs

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[Hogan et al, 2009, MNRAS, 396, 2074]
Planets around WDs?

Mullally et al, 2008

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Imaging Planets

Planets Orbiting HR 8799
(Sept. 2008)

~ 7 M$_{\text{Jup}}$
~ 60 Myrs
T$_{\text{eff}}$ ~ 800 - 1100 K

~ 10 M$_{\text{Jup}}$

Marois et al., 2008

1RXS J160929.1-210524

~ 8 M$_{\text{Jup}}$

~ 5 Myrs
T$_{\text{eff}}$ ~ 1800 ± 200 K

2.2”
330 AU at 140 pc

Lafrenière et al., 2010
Reason 1: Contrast

\[ \Delta L \sim 10,000 \]

White Dwarfs

Main Sequence

Supergiants

Giants

A and B
Reason 2: Resolution
Reason 2: Resolution
Reason 2: Resolution

\[ \frac{M_{\text{MS}}}{M_{\text{WD}}} \]
Why Planets Around WDs?

- Spectroscopy of cool, low mass objects
- Constraints on evolutionary models
- Age of system can be determined without the use of models:
  - white dwarf cooling age
  - mass and lifetime of main sequence progenitor
- Provides model-free benchmark estimates of planetary masses
Degenerate Objects around Degenerate Objects

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The DODO Survey

Gemini North + NIRI wide field of view
Gemini South + FLAMINGOS young white dwarfs
white dwarfs within 20 pc nearby white dwarfs
directly imaging extrasolar planets one hour exposures
white dwarfs younger than 4 Gyr planetary mass companions
multi-epoch observations companions in wide orbits
survey began in 2002 common proper motion companions

Total age = main sequence lifetime + white dwarf cooling age

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Models

• IFMR (Dobbie et al., 2006):
  \[ M_{WD} = 0.133 \, M_{MS} + 0.289 \]

• Main sequence lifetime (Wood, 1992):
  \[ t_{MS} = 10 \left( \frac{M_{MS}}{M_{\odot}} \right)^{-2.5} \, \text{Gyrs} \]

• White dwarf cooling age (Fontaine et al., 2001)

• ‘COND’ evolutionary models for cool brown dwarfs and extrasolar planets (Baraffe et al., 2003)
Imaging Planets

- $M_{MS} \sim 1.5 \, M_{\odot}$
- $M_{WD} = 0.133 \, M_{MS} + 0.289 \rightarrow \sim 0.49 \, M_{\odot}$
- $M_{MS} / M_{WD} \sim 3$
- 24 AU $\rightarrow$ 74 AU
- 38 AU $\rightarrow$ 117 AU
- 68 AU $\rightarrow$ 209 AU
- HR8799 is 39.4 pc away $\rightarrow \sim 1.9 - 5.3''$
A Candidate?

Proper Motion Diagram for WD2007–219

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No Candidate 😞
Another Candidate?

- $M_{WD} \sim 0.7 \, M_\odot$
- $M_{MS} \sim 3.2 \, M_\odot$
- $M_{MS} / M_{WD} \sim 4.5$
- $t_{tot} \sim 1.3 \text{ Gyrs}$
- $d \sim 50 \, \text{pc}$
- $\sim 36'' \text{ away} \rightarrow$
- $r_{WD} \sim 1850 \, \text{AU}$
- $r_{MS} \sim 400 \, \text{AU}$
Perhaps?
Perhaps?
| White Dwarf  | Type | Age [Gyrs] | 50% M [M\textsubscript{Jup}] | 50% T [K] | WD Orbit [AU] | MS Orbit [AU] |
|--------------|------|------------|-----------------|-----------|---------------|---------------|
| WD0115+159   | DQ   | 1.7        | 8 ± 1           | 380       | 46 - 675      | 11 - 160      |
| WD0208+396   | DAZ  | 2.6        | 9 ± 1           | 360       | 50 - 758      | 14 - 138      |
| WD0644+375   | DA   | 2.1        | 8 ± 1           | 360       | 46 - 652      | 17 - 236      |
| WD1055-072   | DC   | 3.3        | 9 ± 1           | 340       | 36 - 503      | 8 - 103       |
| WD1134+300   | DA   | 0.37       | 3 ± 1           | 350       | 46 - 664      | 9 - 127       |
| WD1647+591   | DAV  | 0.91       | 5 ± 1           | 350       | 33 - 372      | 7 - 77        |
| WD1900+705   | DAP  | 1.1        | 5 ± 1           | 350       | 39 - 452      | 8 - 89        |
| WD1953-011   | DAP  | 2.1        | 8 ± 1           | 360       | 34 - 509      | 7 - 111       |
| WD2007-219   | DA   | 1.4        | 7 ± 1           | 370       | 55 - 831      | 12 - 189      |
| WD2326+049   | DAZ  | 1.1        | 6 ± 1           | 370       | 41 - 396      | 9 - 89        |
More Results

- The DODO survey can detect companions $\geq 500$ K around all targets.

- $\leq 4\%$ of white dwarfs have substellar companions with $T_{\text{eff}} \geq 500$ K between projected physical separations of 60 - 200 AU (20 - 45 AU around MS progenitors.)

- $\leq 8\%$ of white dwarfs have companions with masses above the deuterium burning limit ($\sim 13$ M$_{\text{jup}}$)

- $\leq 9\%$ have companions with masses $\geq 10$ M$_{\text{jup}}$
### Other surveys

| Survey                        | Targets      | Number of targets | Limit \( (M_{\text{Jup}}) \) | Separation (AU) | Frequency of companions (%) |
|-------------------------------|--------------|-------------------|-------------------------------|------------------|----------------------------|
| McCarthy & Zuckerman (2004)  | G K M        | 102               | >12                           | 75–300           | 1 ± 1                      |
|                               |              | 178               | >30                           | 140–1200         | 0.7 ± 0.7                  |
|                               |              |                   | 5–10                          | 75–300           | <3                         |
| Farihi et al. (2005)          | White dwarfs | 261               | >52                           | 100–5000         | < 0.5                      |
|                               |              | 86                | >21                           | 50–1100          | < 0.5                      |
| Allen et al. (2007)           | M7–L8        | 132               | >52                           | 40–1000          | < 2.3                      |
| Lafrenière et al. (2007)      | F G K M      | 85                | 13–40                         | 25–250           | < 5.6                      |
| Nielsen et al. (2008)         | A F G K M    | 60                | >4                            | 20–100           | <20                        |
Future Work

• Larger sample size
• Deeper images
• First epoch images for 10 new targets
• Watch this space!