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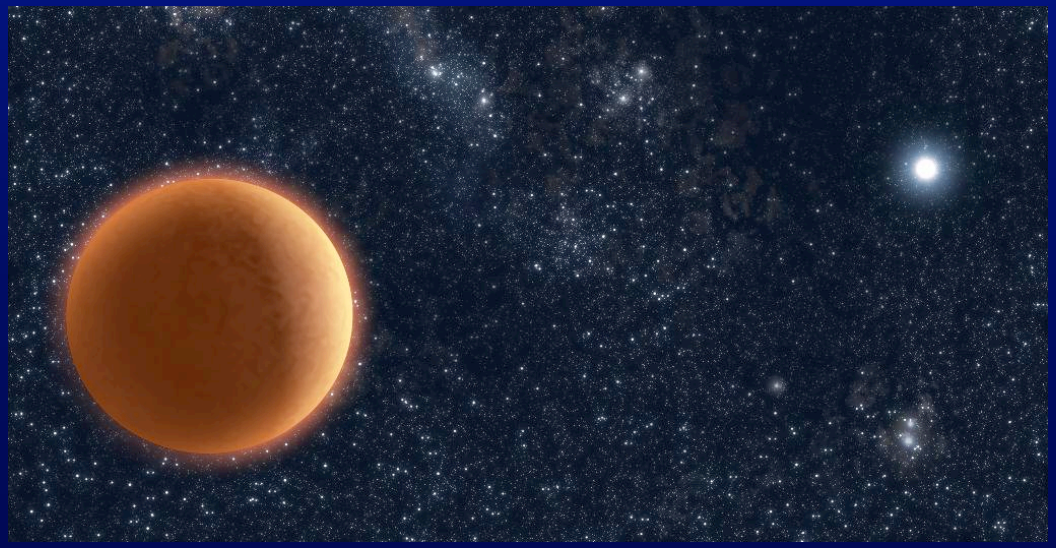
DEPARTMENT OF PHYSICS AND ASTRONOMY

Planets around white dwarfs

Matt Burleigh



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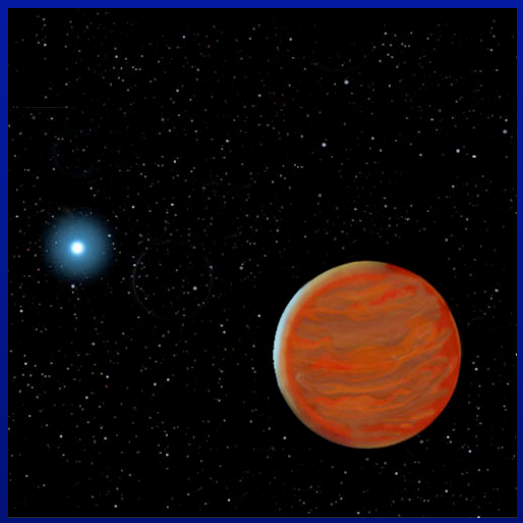
Contents

- Original motivation
- DODO - results from our direct imaging survey
- Where do we go next?
- The role for E-ELT

Direct imaging of planets around white dwarfs

- Ideal targets for direct imaging (and spectroscopy) of exoplanets:
  - Improve contrast problem: WDs up to ~10^4x fainter than their progenitors
  - Improve resolution problem through widening of orbits
    - *M(MS) / M(WD) (Jeans 1924)*
  - Indirectly study planetary systems around WD progenitors: early-type stars (B,A,F), intermediate masses ($1.5<M<8M_{sun}$)
  - White dwarfs common in solar neighbourhood
  - *White dwarf ages are well constrained*
- Planetary companions of WDs will be old, mature gas giants
  - $200 < T_{eff} < 600K$
  - > few x 10^8 years old
  - Detectable at ages up to several Gyr



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Direct Imaging Searches Around White Dwarfs: The DODO project

Degenerate Objects around Degenerate Objects

With Emma Hogan (now Gemini South) and Fraser Clarke (Oxford)

Burleigh et al. 2008, MNRAS, 386, L5
Hogan et al. 2009, MNRAS, in press arXiv:09010532

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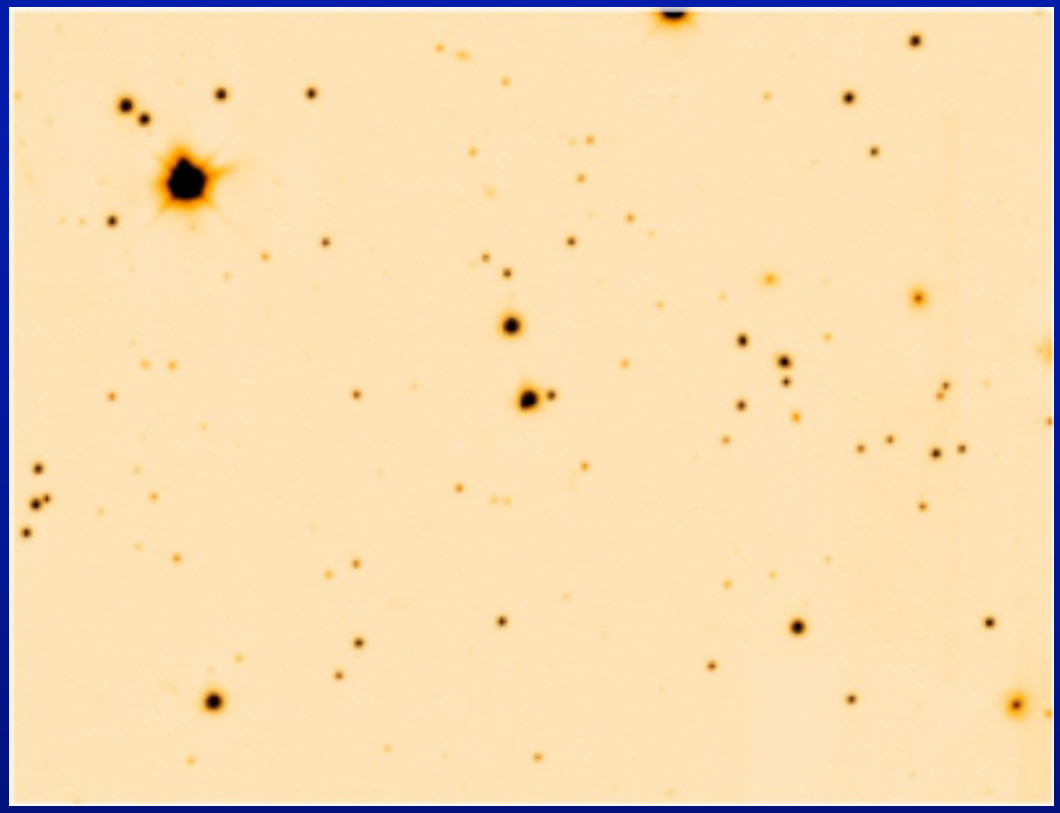
Strategy

- Selected young (<3Gyr), nearby (<20pc) WDs
  - (0.2”yr < PM < few “/yr)
  - Sample ~40 stars
- Obtained deep wide near-IR (J) images with Gemini and VLT
  - Total exp time ~1hr
  - Depth J~22-24
  - Image quality typically 0.4”-0.7” (no AO!)
  - Search for candidates outside 3” radius from WD
- Wait 1 — 3 years…
  - Obtain 2nd epoch images of all systems to check for common proper motion companions
- Probe range of separations from <10AU to >1000AU
- Sensitive to masses >few M_{Jup}



^

~90”

V

< ~120” >

- Two epochs
  - WD motion ~1” between images
  - Image depth J~23.5

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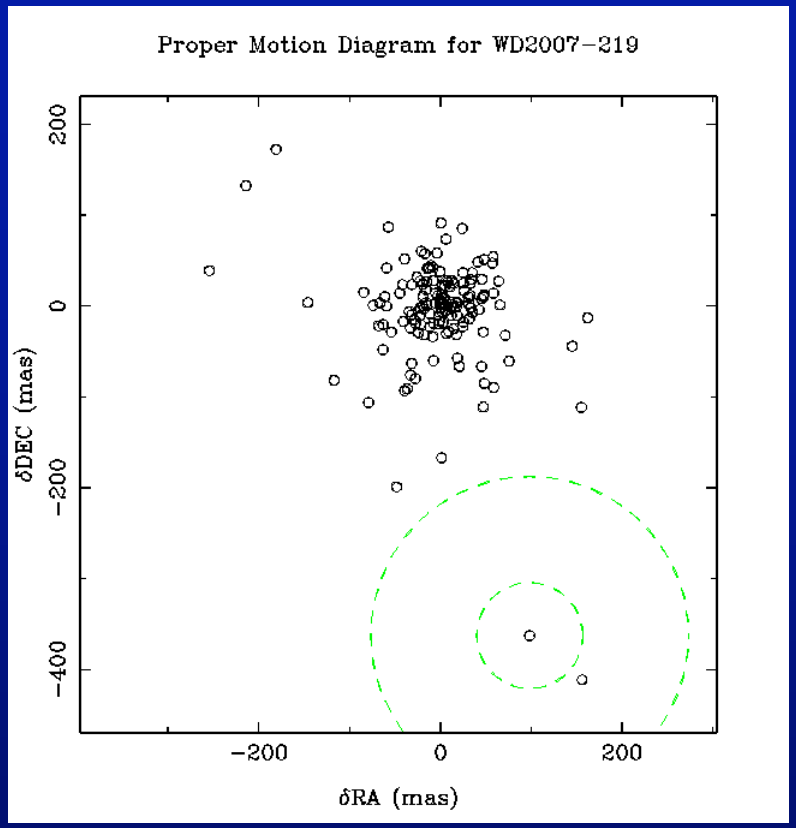
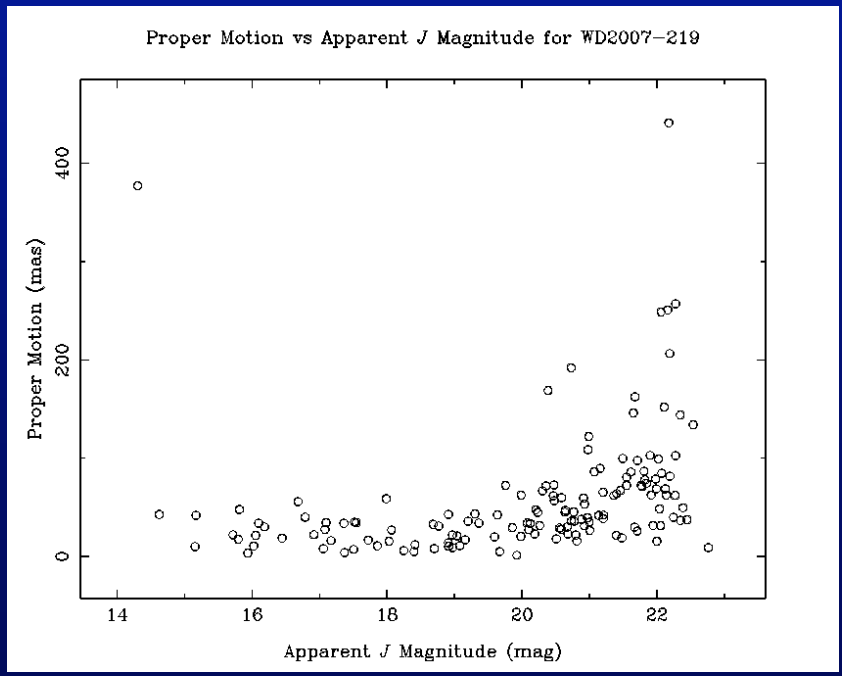
A candidate?





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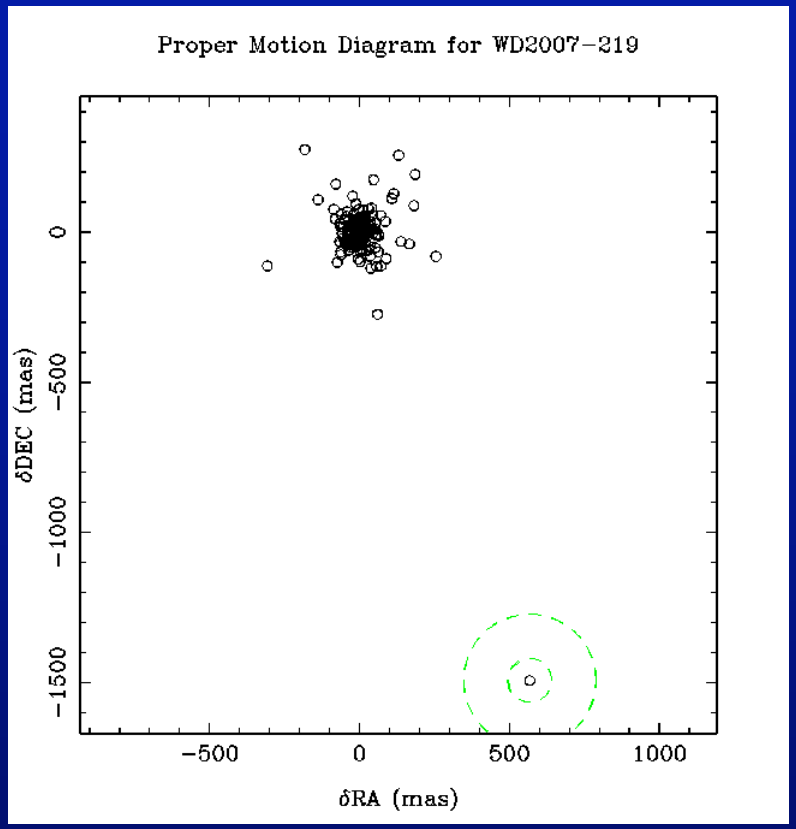
No candidate :(



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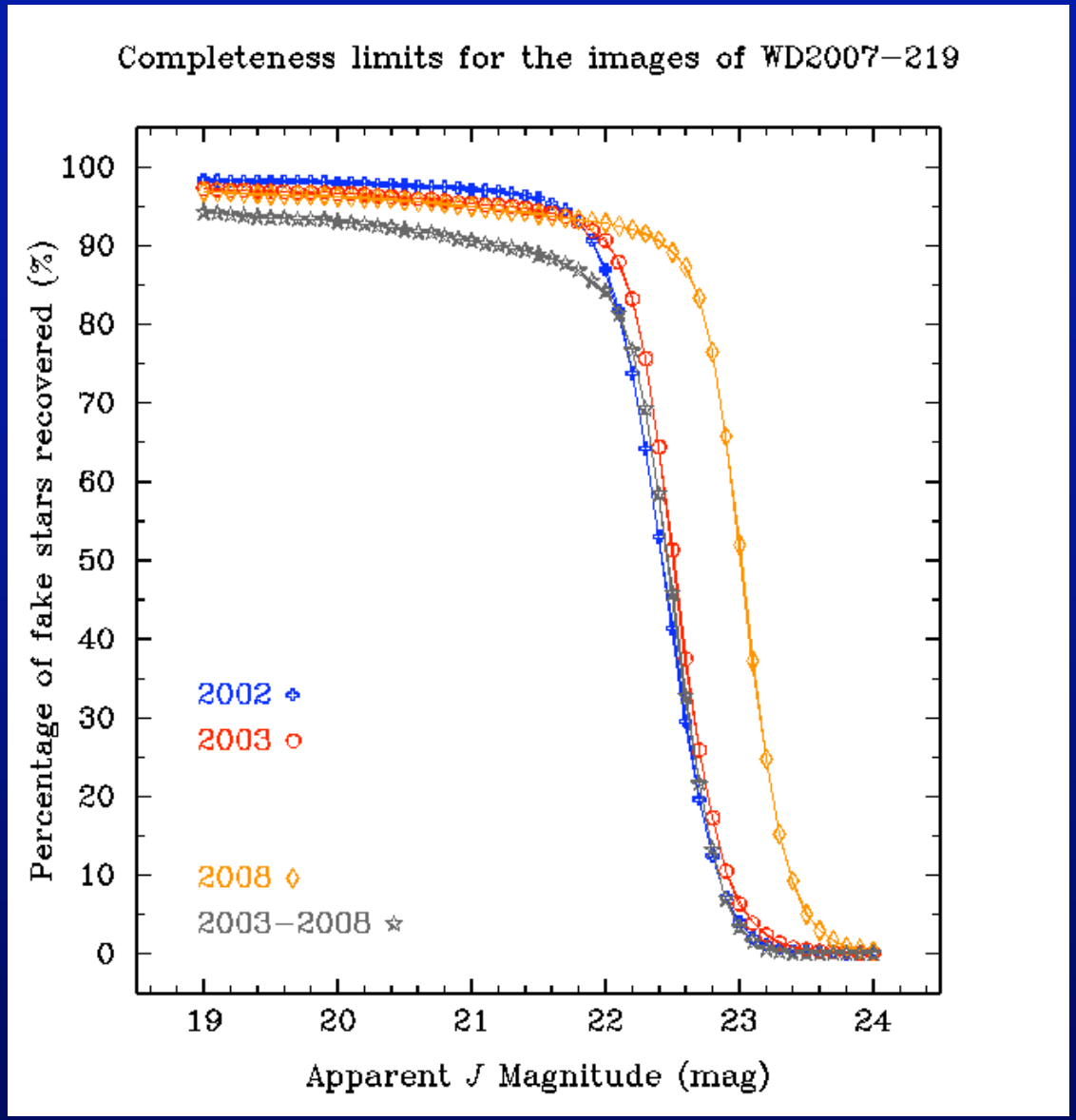

- 50% completeness limit -> $7M_{Jup}$

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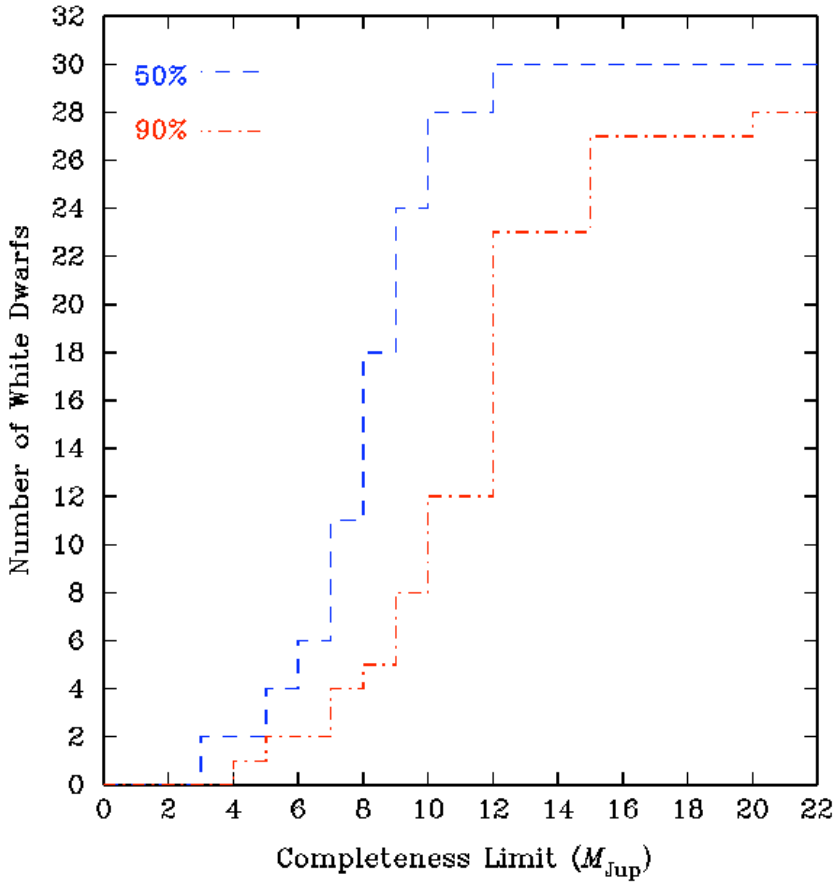

- <5% of WDs have resolved substellar companions above deuterium burning limit (13M_{Jup})
- <7% of WDs have resolved substellar companions >10M_{Jup}
- <1/3rd of WDs have resolved substellar companions >6M_{Jup}

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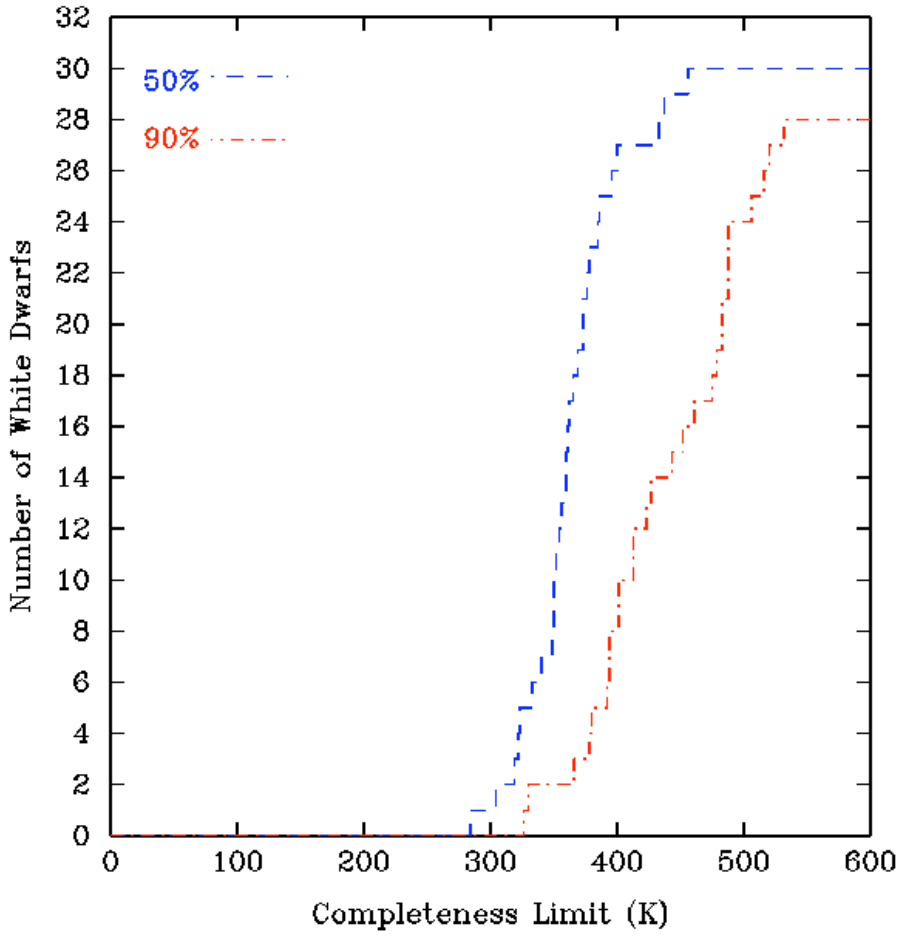

- <4% of WDs have resolved substellar companions >500K
- <7% of WDs have resolved substellar companions >400K

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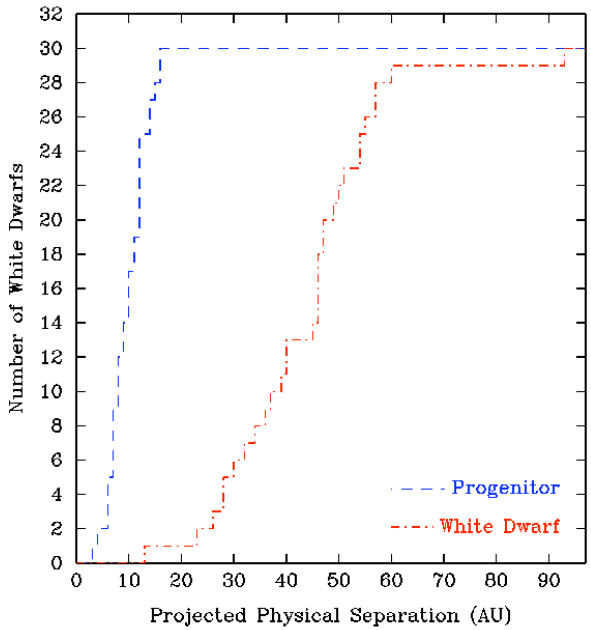
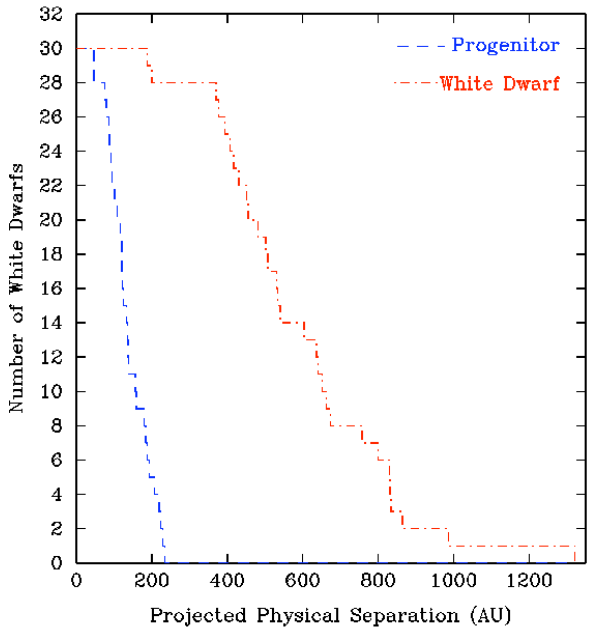
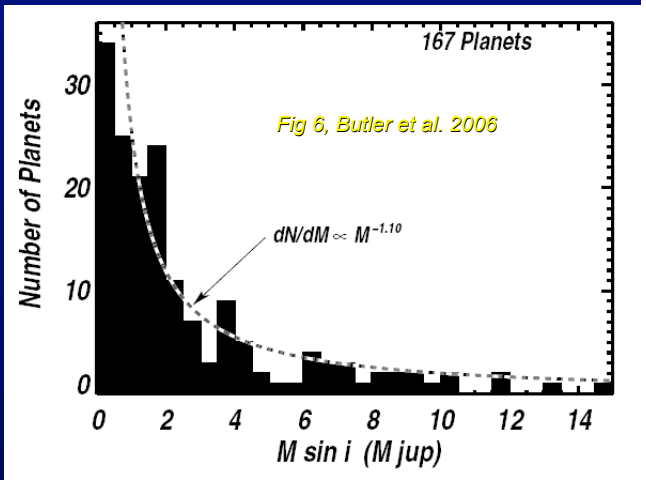

Number of White Dwarfs
Projected Physical Separation (AU)
Progenitor
White Dwarf


Number of White Dwarfs
Projected Physical Separation (AU)
Progenitor
White Dwarf

White dwarf surveys: results

- The current imaging searches at WDs are rarely sensitive to <6M_{Jup}
- Lack of detections consistent with conclusions of Gemini Deep Planet Survey :
  - At 95% CL, fraction of stars harbouring a planet >5M_{Jup} between 25 and 300AU <0.091
- But from evolved giant stars Lovis & Mayor (2007) conclude that >3% of stars M>1.8M_{sun} have planets >5M_{Jup}
- And frequency of dust disks suggests >7% of WDs possess old planetary systems (Jura 2006)
- Also rv exoplanet mass distribution dN/dM ~ $M^{-1.1}$ (Butler et al. 2006)
  - Planets >6M_{jup} are relatively rare
- Where do we go from here?:
  - Must probe to lower masses, and target more stars
  - Spitzer warm mission, ex-AO instruments, JWST, ELT



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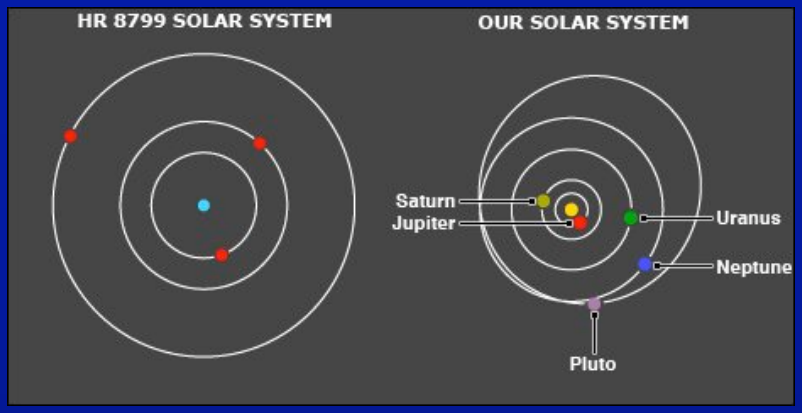
HR8799 as a white dwarf…



- HR8799: A5V 1.2-1.8M_{jup} 39pc 30-160Myr old
- Planets: 7M_{jup} @ 68AU, 10M_{jup} @ 38AU, 10M_{jup} @ 24AU

- Will evolve after 1.75Gyr to a 0.58M_{sun} white dwarf
- Planet orbits expand by factor ~3 to ~200AU,~120AU & 75AU

- Let WD cool to 10,000K over ~0.5Gyr….system age now 2.25Gyr…
- 10M_{jup} planet will be J=23.8 @39pc, or J=22.4 @ 20pc
  - *At 20pc or less, would have been detected in DODO*

  - *How common are HR8799-like systems?*

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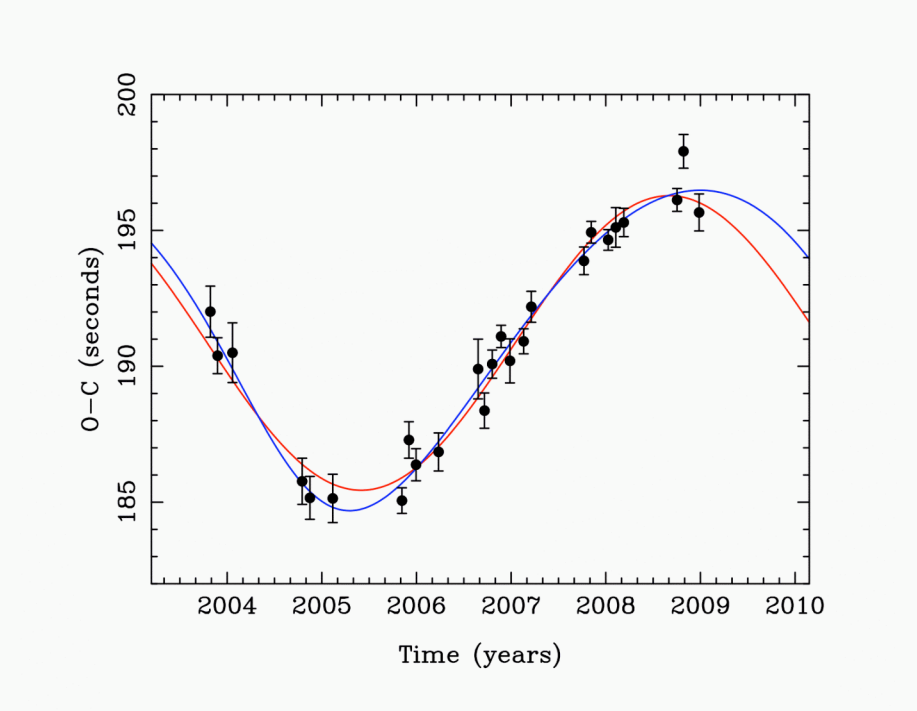
A planet around a pulsating WD



- GD66 is a non-radial pulsating WD
- Pulsation modes and frequencies extremely stable
- Periodic variations in pulse arrival times
- Best fit by 2.3M_{jup} planet in 6.8yr orbit
  - *Mullally et al. 2008, ApJ, 676, 573*
- cf 3M_{jup} planet found at pulsating hot subdwarf V391 Peg
  - *Silvotti et al. 2007, Nature, 449, 189*

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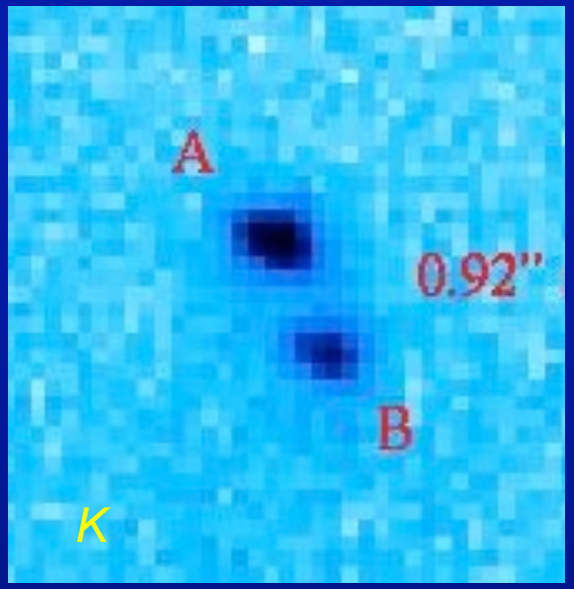
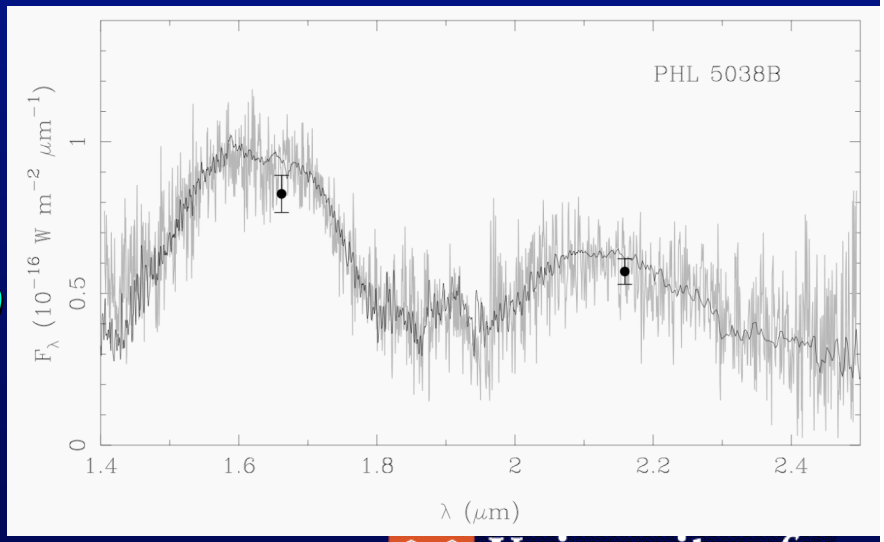
PHL5038 = SDSS J222030.68-004107.3

- *B*=18, UKIDSS *K*=16.7
- Resolved at 0.92” (=55AU projected)
- L8 companion (T~1500K, M~0.055Msun)
- WD T=8000+/-100K, M=0.72+/-0.15Msun, d=64+/-10pc
  - *Total age 1.9-2.7Gyr*
- 2nd known wide WD+BD binary
  - *Benchmark at L-T transition*
  - *Steele et al. 2009, arXiv:0903.3219*





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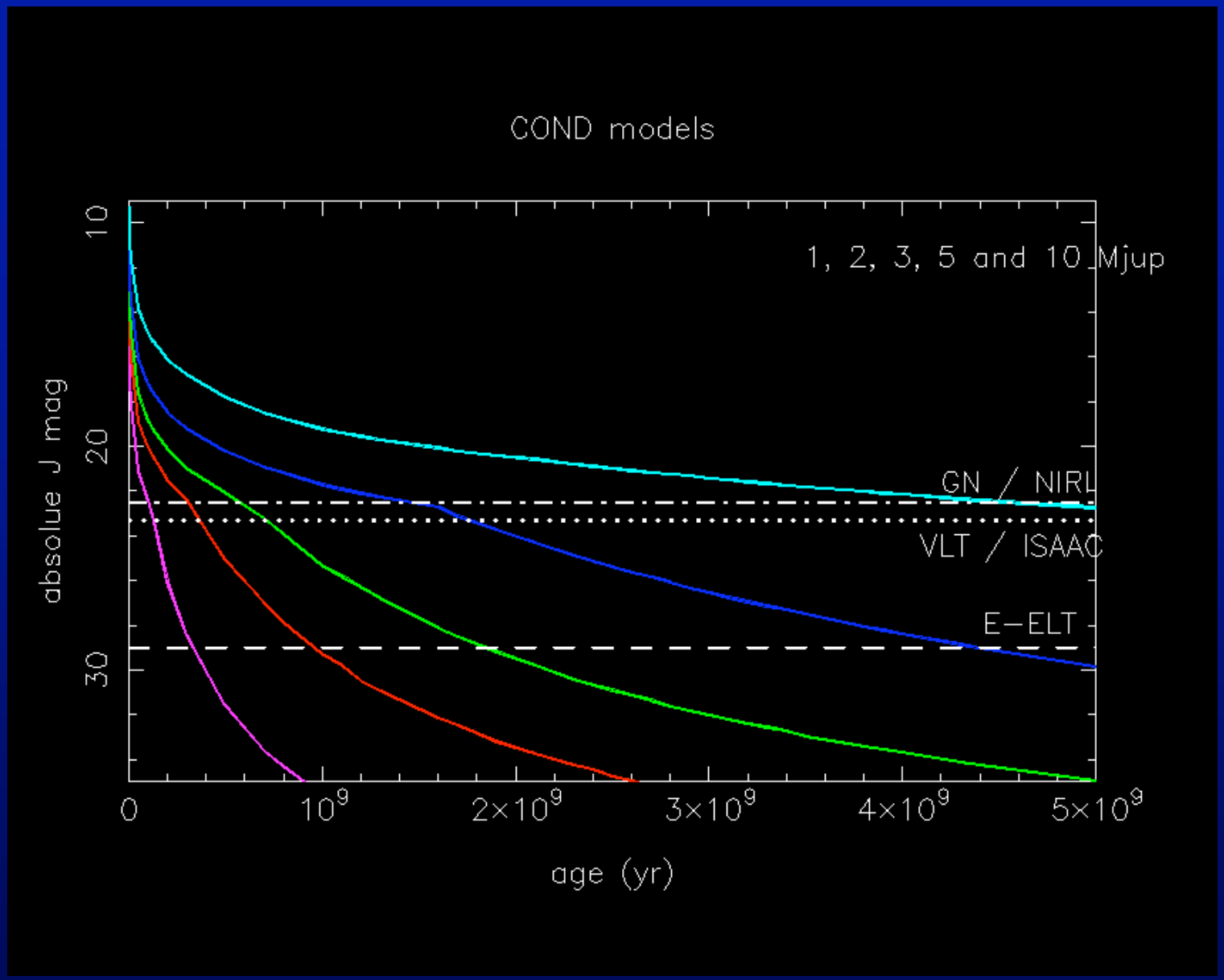

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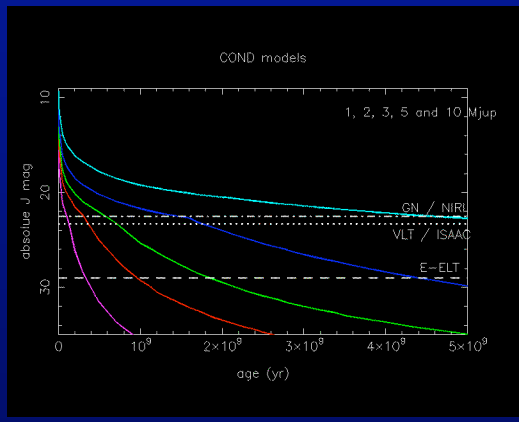
A search for old planets at WDs with E-ELT

- Survey up to 100 WDs within 20-50pc
  - Include Hyades WDs, massive young WDs
  - Wide, common proper motion companions
- Total ages < 2Gyr
- Sensitivity to at least $3M_{Jup}$
  - 1Mjup in some cases
- Wide area
  - Orbital evolution, no need for coronagraph
  - MICADO, J-band, one hour exposure
- For close companions, EPICS + Coronagraph
- Caveat: JWST can do better in mid-IR



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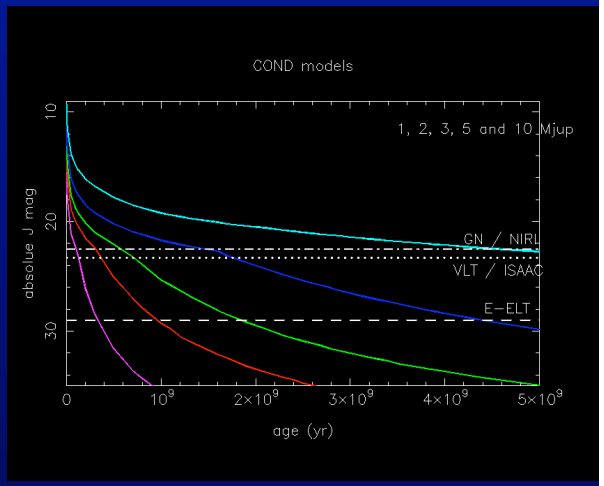
Characterisation of old planets at WDs with E-ELT

- Pre- and post-JWST searches:
  - Spitzer warm mission (90 targets)
  - Subaru/HiCiao and other ground-based programmes
  - Pulsating WDs (pulsation timing)
  - GAIA, SIM-Lite astrometry
- Follow-up near-IR imaging and spectroscopy with E-ELT



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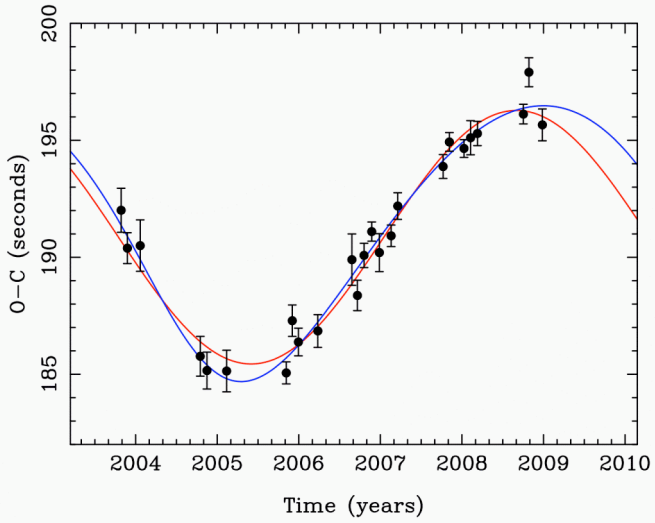
Characterisation of old planets at WDs with E-ELT

- GD66b:
  - M sin i = 2.3M_{jup}
  - 3AU orbit (6.8 years)
  - @51pc, projected separation = 0.06”
  - 1.2-1.7Gyr total age
- Assuming true mass = 3$M_{jup,}$ 1.2Gyr old:
  - J=29.8, H=29.3
- The WD GD66 itself:
  - J=15.70, H=15.66
  - Contrast ~5x10^5
- EPICS?
  - Resolve, map orbit
  - Near-IR photometry (few hours), spectroscopy (?)



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Conclusions

- While direct imaging searches for planets at WDs have been unsuccessful so far, a larger sample size and greater depth is required
- A post-main sequence HR8799-like systems would be detectable within 20-30pc *now*
  - *But how common are they?*
- Pulsation timing may have found 1st planet at a WD
- WDs remain excellent targets for exoplanet searches
  - Low intrinsic luminosity
  - Orbits evolve outwards in giant phases
- Gas giants in wide orbits at WDs may be benchmark objects for testing evolutionary and atmospheric models at older ages (>few x10^8 yr)
- Role of E-ELT and JWST:
  - *Identify post-main sequence planetary systems*
  - *Confirm those found by other techniques (pulsation timing, astrometry [Gaia, SIM-Lite])*
  - *Spectroscopy of benchmarks*

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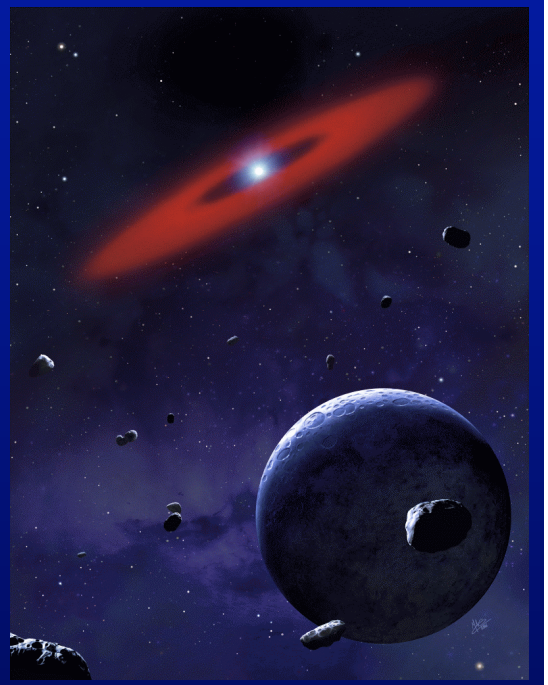
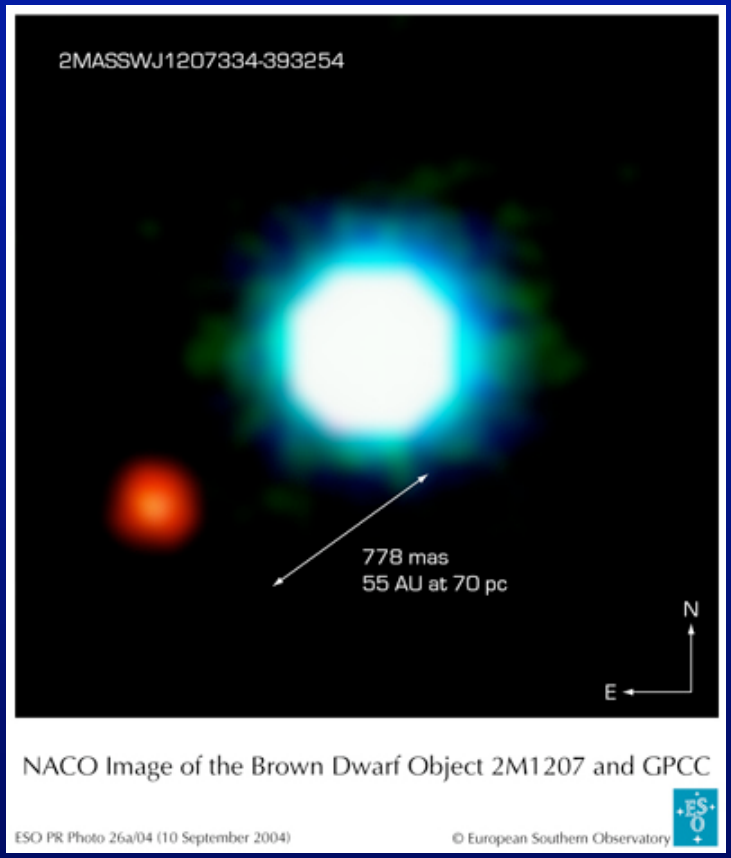
Evidence for old planetary systems

1. Planets have been found by radial velocity technique around evolved giant stars
   - 9% of stars $1.3<M<1.9M_{sun}$ have planets (Johnson et al. 2007)
   - >3% of stars $M>1.8M_{sun}$ have planets $>5M_{Jup}$ (Lovis and Mayor 2007)
2. White dwarfs have been identified as wide companions of planet-hosting stars
   - eg CD-38 10980 (Mayor et al. 2004), eps Ret (Raghavan et al. 2006, Chauvin et al. 2006)
3. Metal-rich circumstellar dust and gas disks discovered around white dwarfs
   - Most likely from asteroids
   - Requires giant planet perturbers
   - Suggests >7% of WDs have old planetary systems (Jura 2006)



Direct imaging of mature exoplanets

- Most convincing case of a directly imaged exoplanet is 2MASS1207
  - Young: ~10^7 years old, ~$5M_{Jup}$
  - wide binary with a ~$25M_{Jup}$ BD
  - late M spectral type, T_{eff}~2000K
  - Chauvin et al. (2004, 2005)
- Planetary companions of WDs will be old, mature gas giants
  - 300 < T_{eff} < 600K
  - > few x 10^8 years old
  - previously unobserved class of object
  - Later than T8.5 (650-700K): Y dwarfs?



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Comparison with Spitzer limits on unresolved companions

(Farihi et al 2008, 34 targets)

	DODO (*resolved, >few 10s AUs*)	Spitzer (*unresolved, <few 10s AUs*)
$>13M_{Jup}$	<5%	<3%
$>10M_{Jup}$	<7%	<4%
$>6M_{Jup}$	<1/3	<12%