Searching for Planets Around White Dwarf Stars

- or -

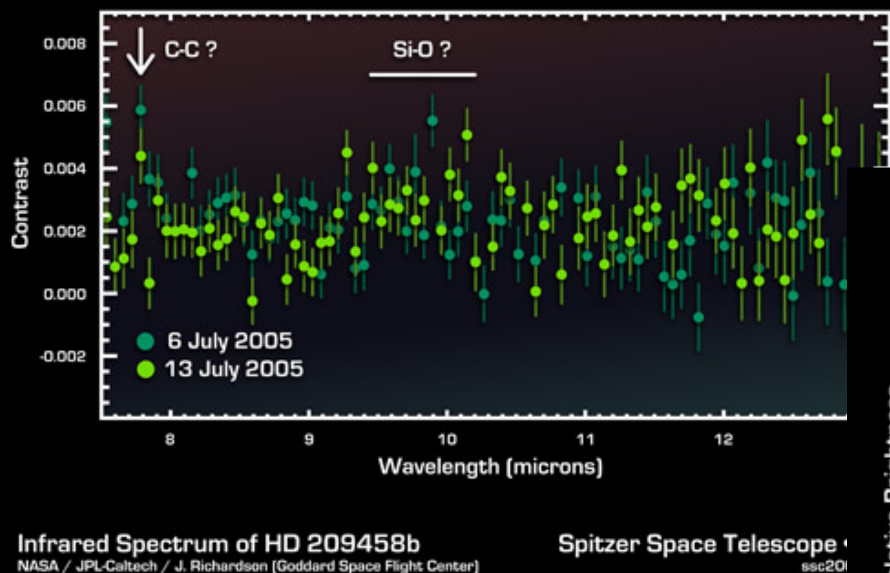
I still haven't found what I'm looking for

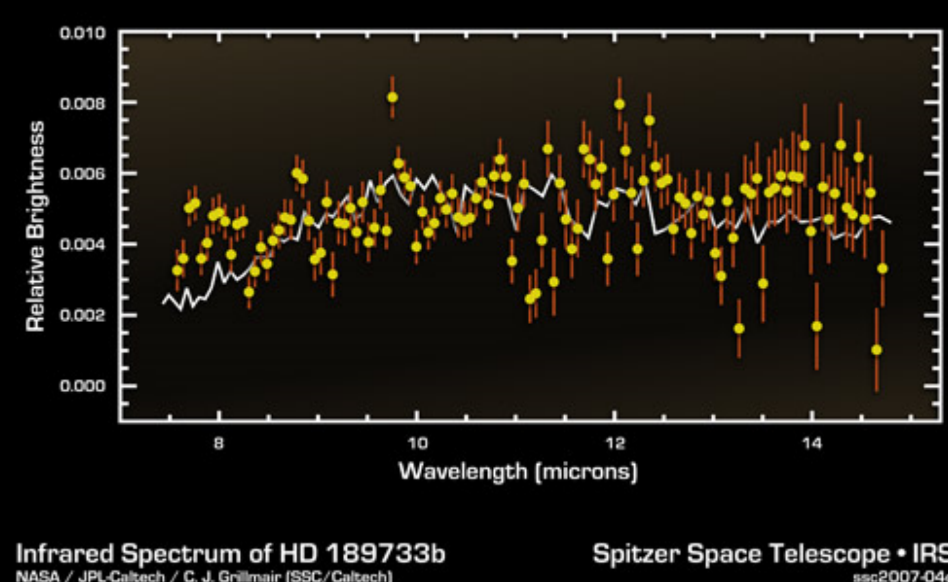
Fergal Mullally

Princeton

The Big Goal

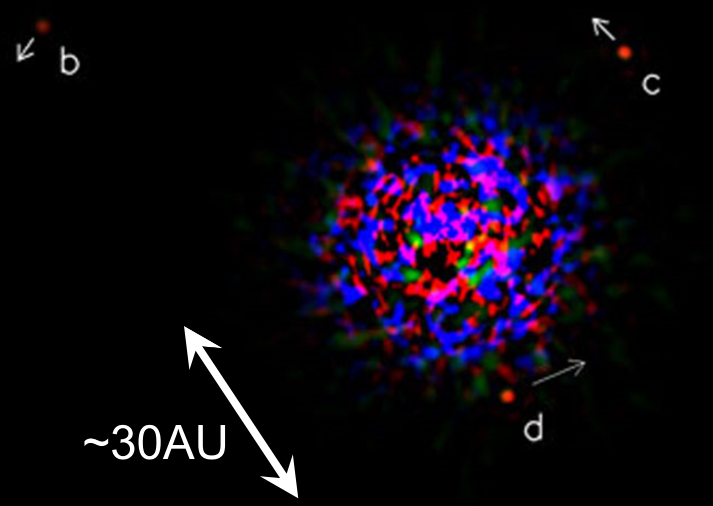
Direct Detection of Extra-solar planets



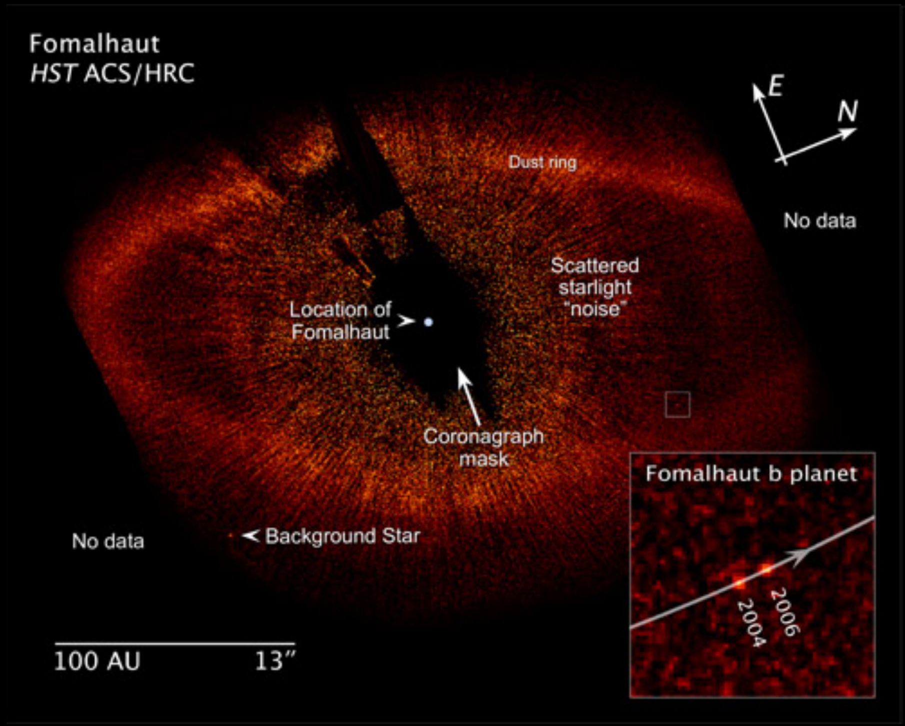


The Big Challenge:

Need high contrast observations:



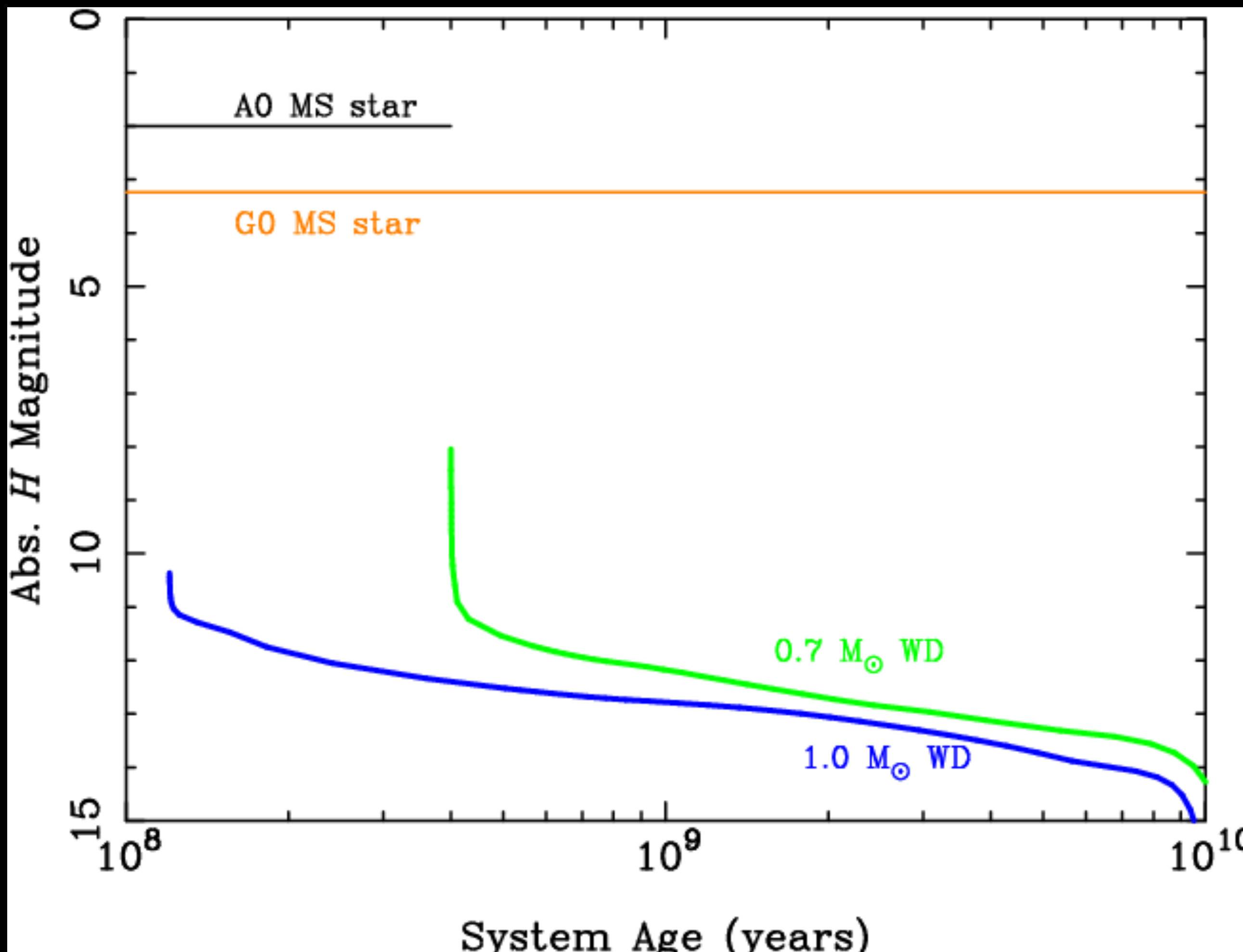
HR 8799 (Marois et al 2008)



Formalhaut (Kalas et al. 2008)

White Dwarf Stars

mitigate our chief constraint



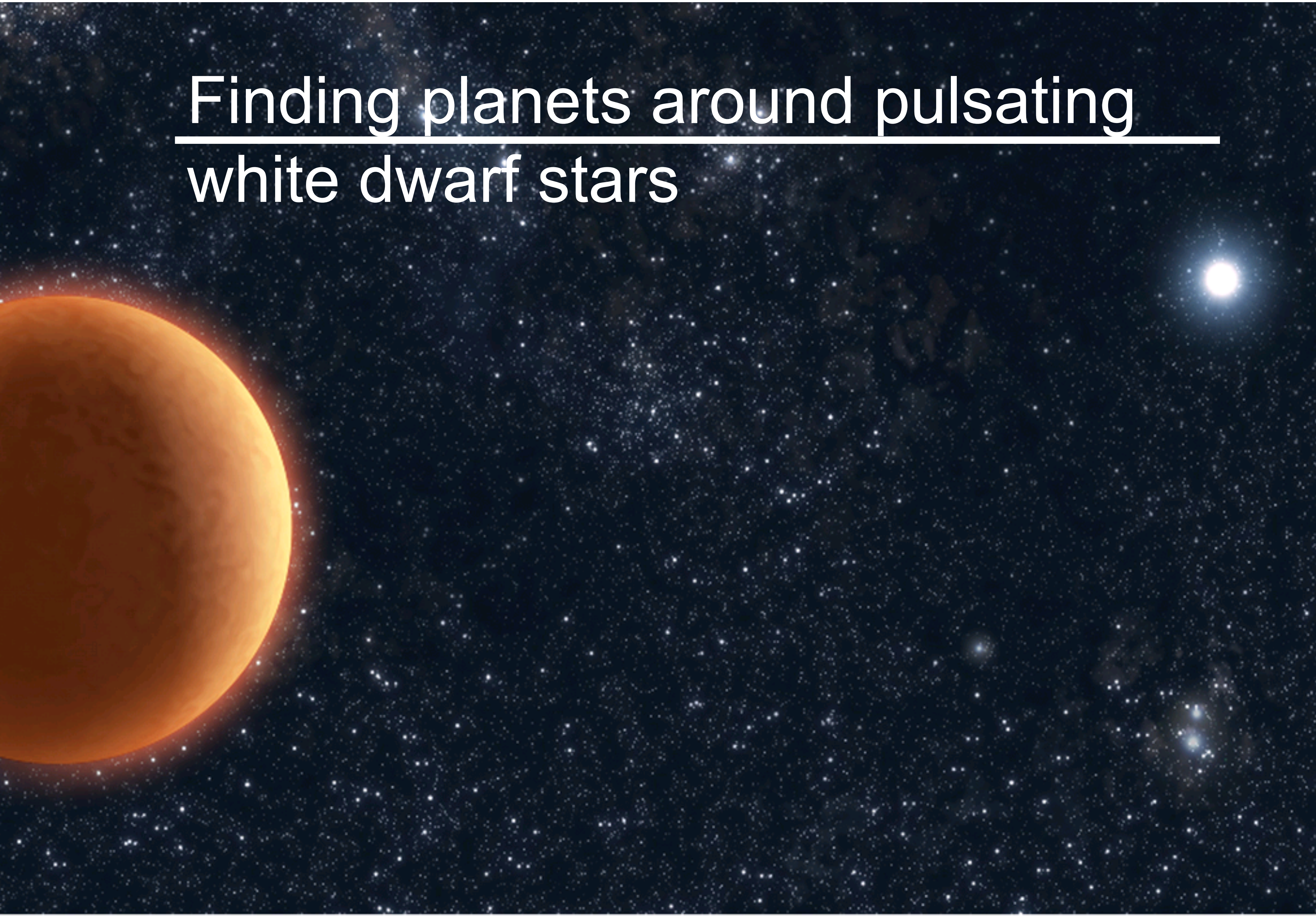
Other advantages

• High proper motions

• Improved contrasts for high mass progenitors

• Different age range (10^8--10^9 yr), compared to young MS stars

Finding planets around pulsating white dwarf stars

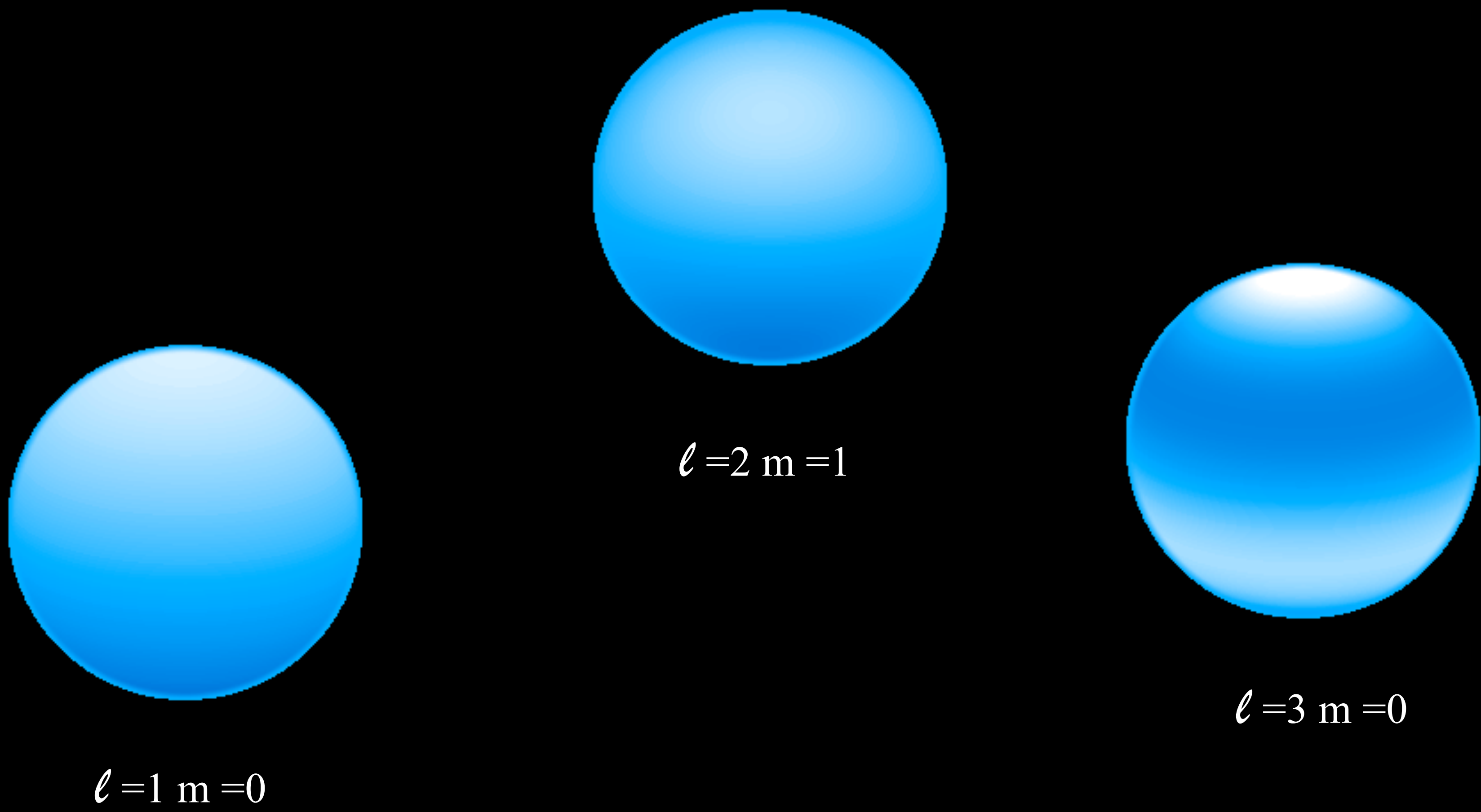


White Dwarf Stars

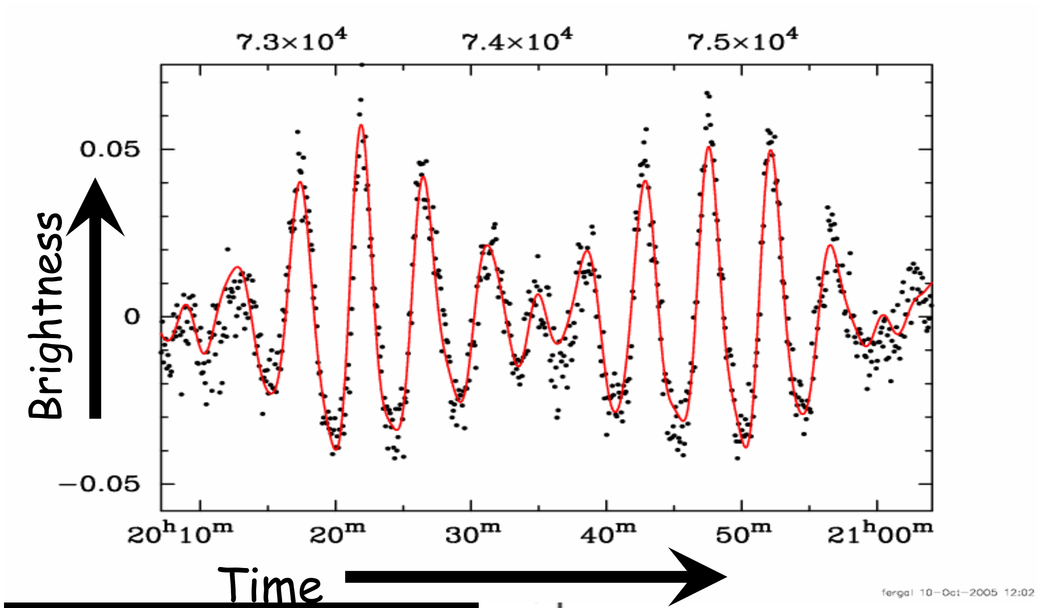
A brief review

- All stars with $M < 8\text{-}10\ M_{\odot}$ will eventually become white dwarf stars
    - That's ~ 98 % of all stars
- Progenitor systems live for 10^8-10^{10} years, and age can be estimated
- Faint: L* ~ 10-3--10-4$L_{\odot}$
- WD planets at larger orbital separations than progenitor star
- Few, very broad absorption lines
    - Unsuitable for precision radial velocity measurements
- Instrumentation coming on-line now that can detect Jovian analogues around WDs (GPI, HiCIAO).

DAVs are multi-periodic, non-radial pulsating white dwarf stars

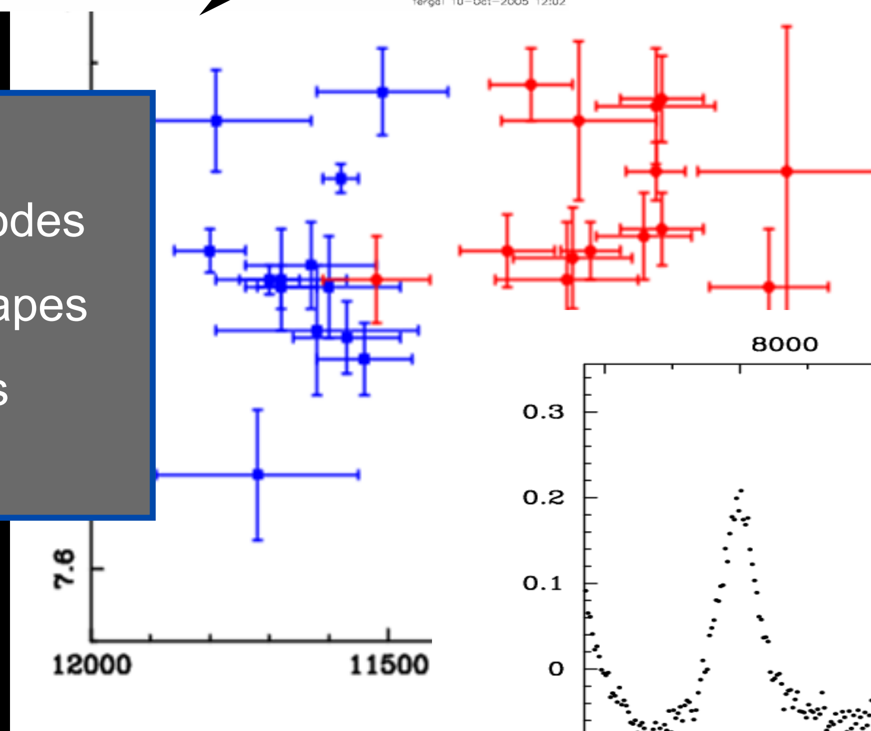


two sub-types



hDAVs

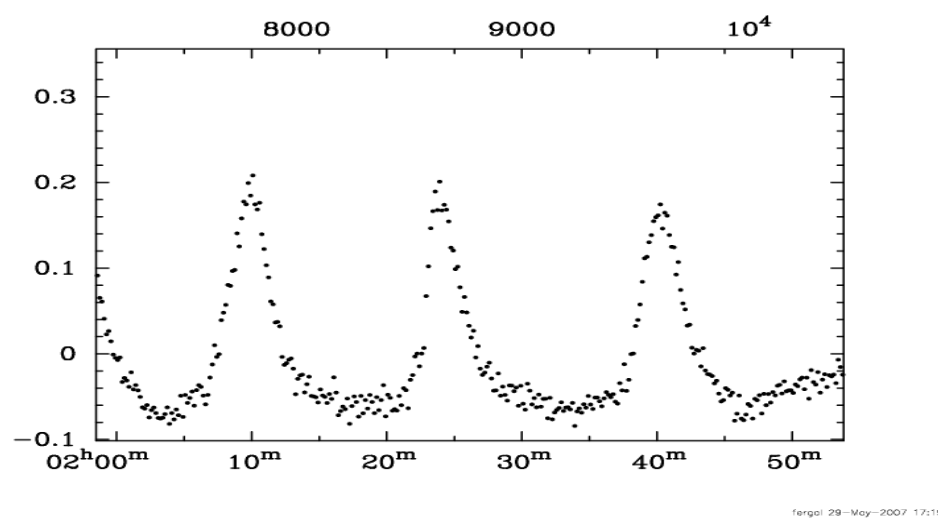
- Small number of modes
- Symmetric pulse shapes
- Periods of 100-400s
- Low amplitude



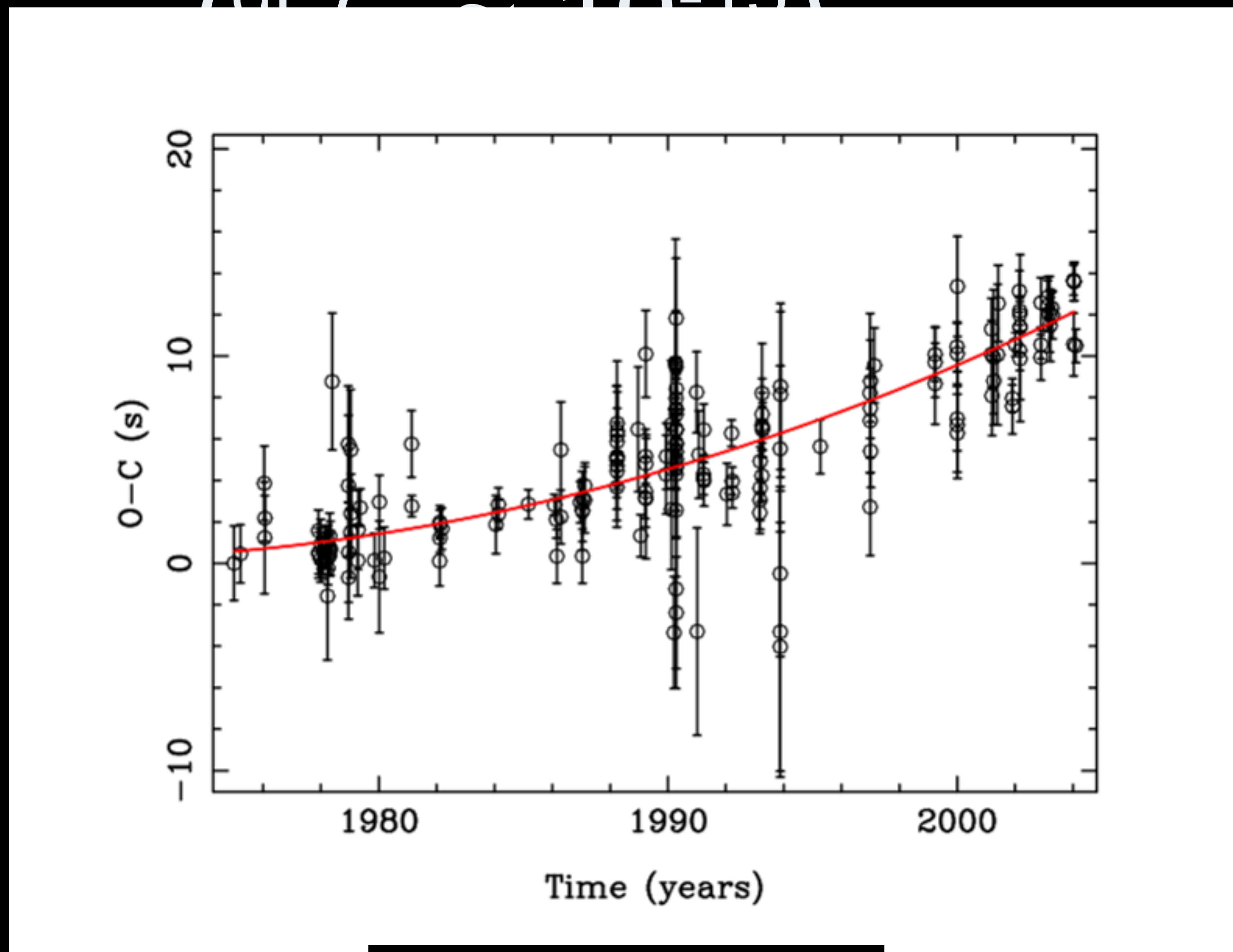
cDAVs

- Often many modes
- Sharply peaked pulse shapes
- 500-1000s

amplitude



Some DAVs show extreme stability in phase of pulsation (dP/ ~ 10-15)



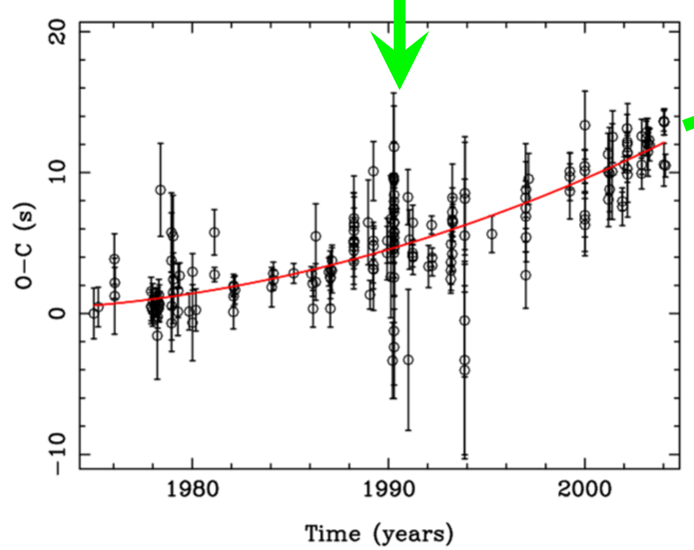
25 years of data

Kepler et al. (2005)

Cooling of the star causes a *monotonic* increase in period

...which causes a parabolic trend in arrival time

Avg. atomic mass of nucleons in core



...which can be used to measure core composition...

$$\dot{P}(A) = (3\text{–}4) \times 10^{-15} \frac{A}{14} \text{ s s}^{-1}.$$

Kepler (2005), Kawalar (1986)

rate of period change

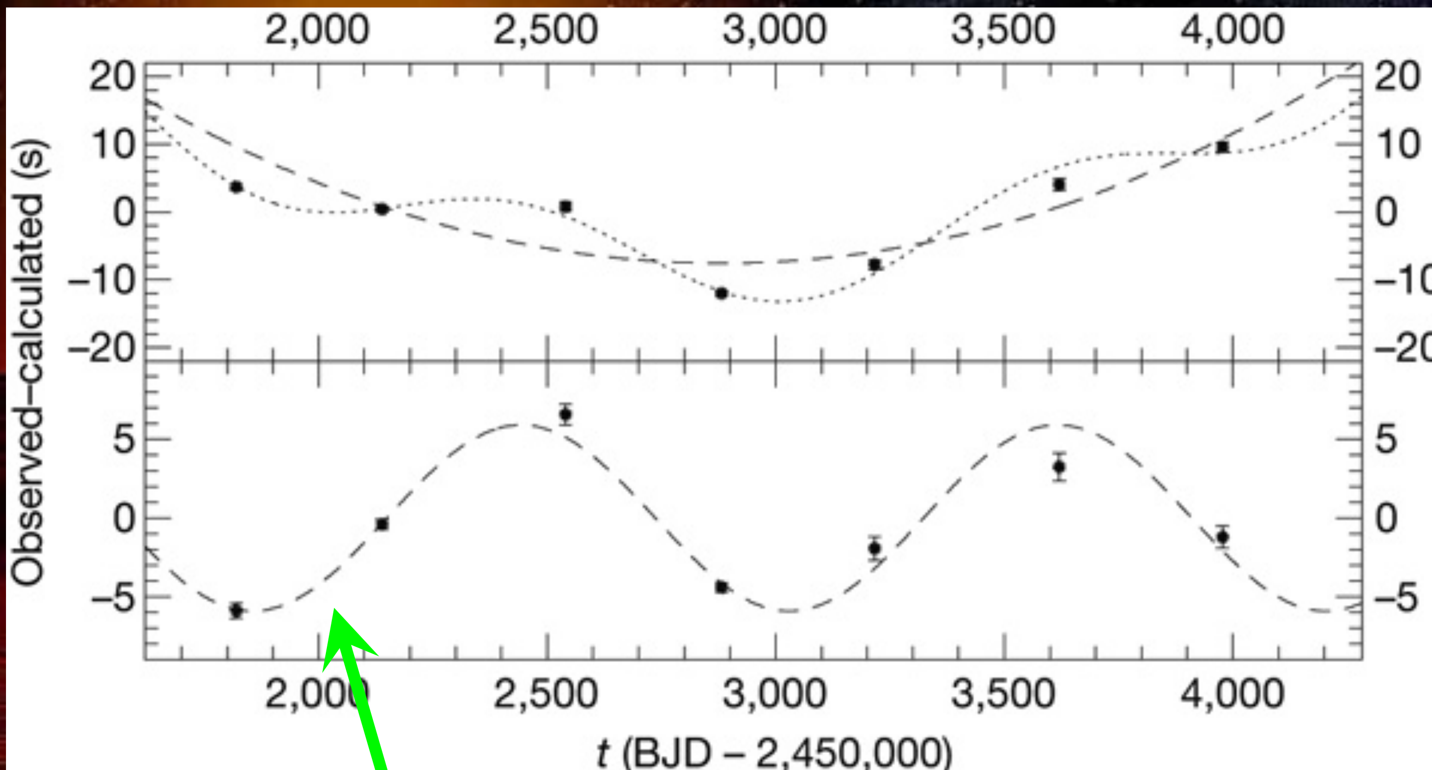
...which can be used to test models of stellar evolution

- Change in arrival time (O-C) greater for planets with:
  - Large Mass
  - Large orbital Separation
  - Orbits along our line of sight.

$$\tau = \frac{2\, a\, m_p \sin(i)}{M_* c}$$

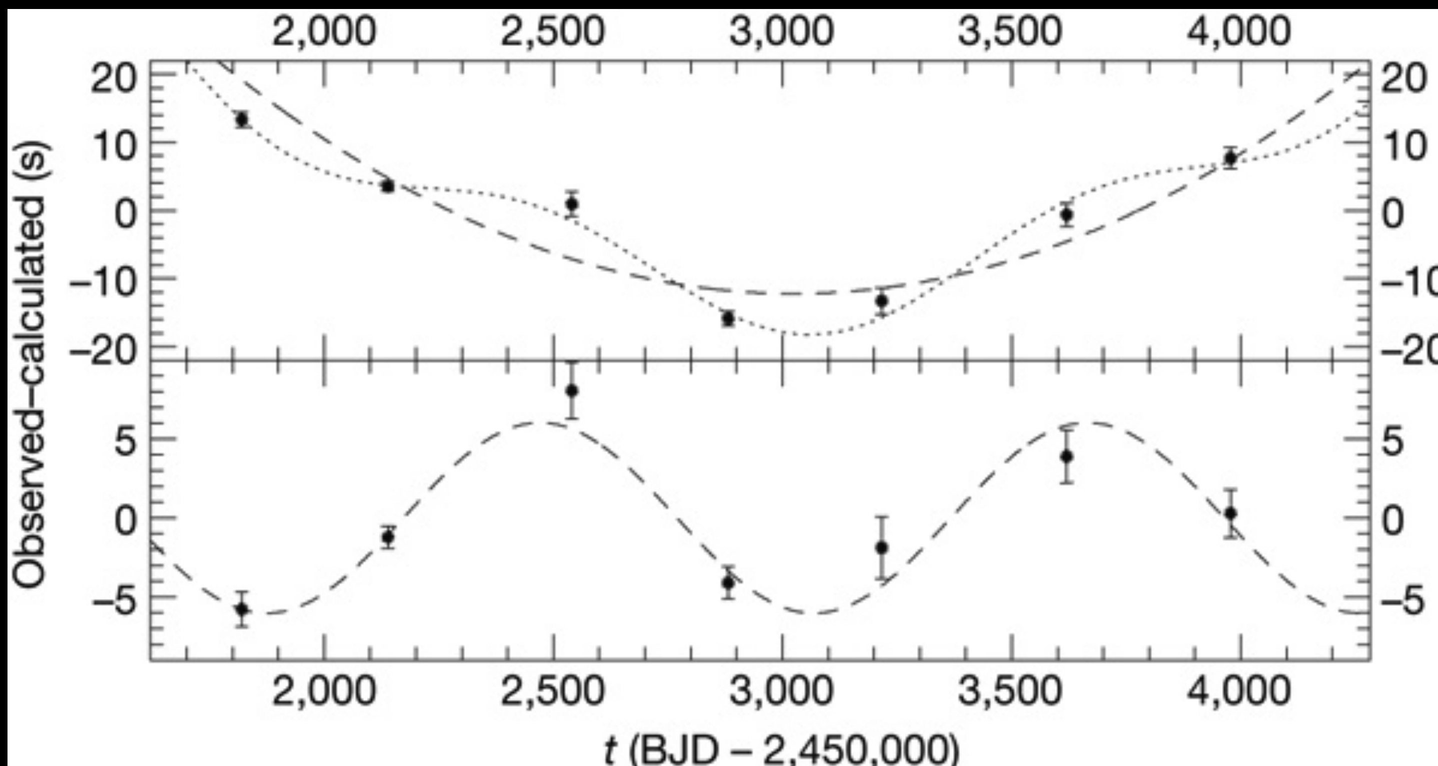
Distance from Earth

A planet around an sdB star



Silvotti et al. (2007)

O-C values after effect of secular cooling removed



2,000
2,500
3,000
3,500
4,000
20
10
0
−10
−20
5
0
−5
Observed−calculated (s)
t (BJD − 2,450,000)

The McDonald Observatory

WD Planet Search Program

Mullally et al. (2008)

Sample of 15 DAVs with the 2.1m Otto Struve telescope at McDonald Observatory

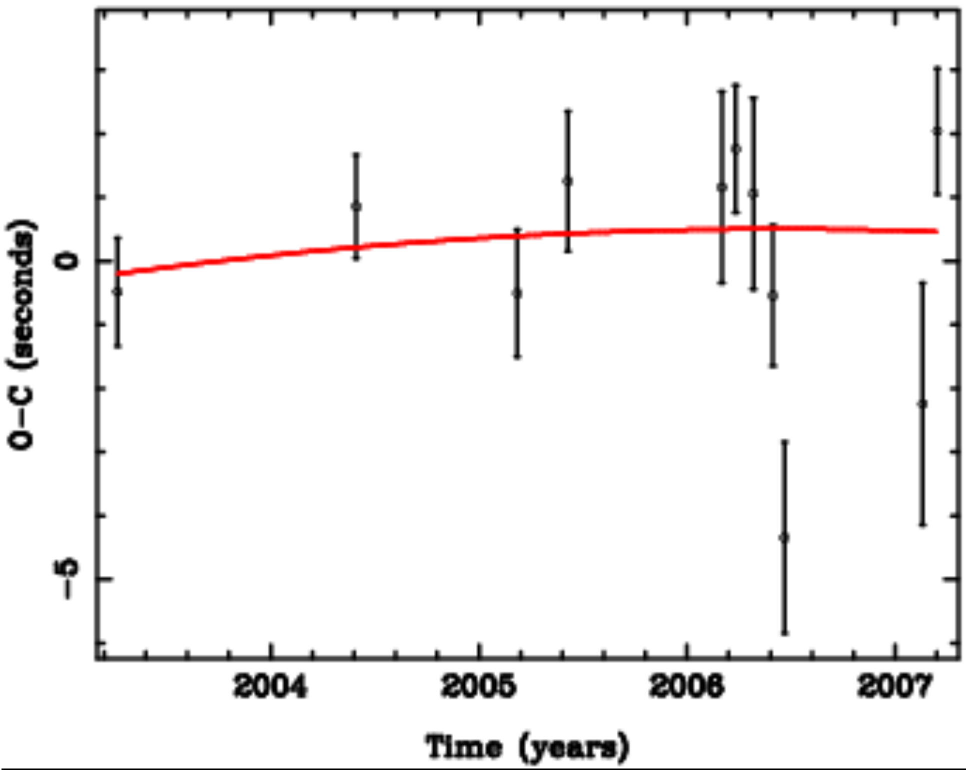
Searching for planets through variations in the pulsation arrival time (same as Silvotti 2008)

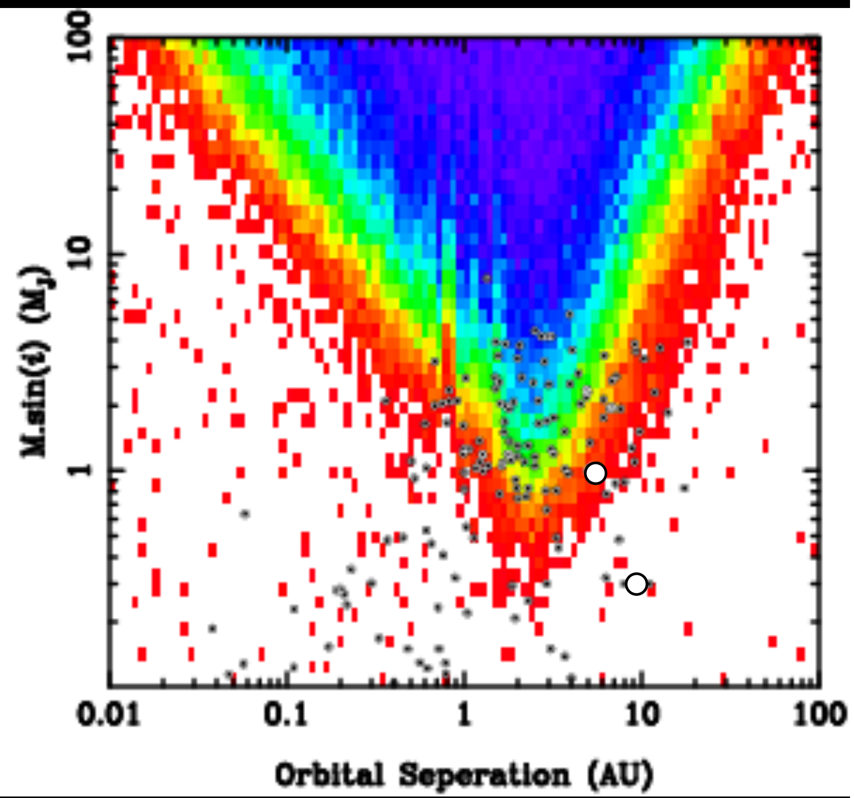
Data spans 2003 to 2009 with timing uncertainties of 0.5--2 seconds

McDONALD OBSERVATORY
THE UNIVERSITY OF TEXAS AT AUSTIN

Results

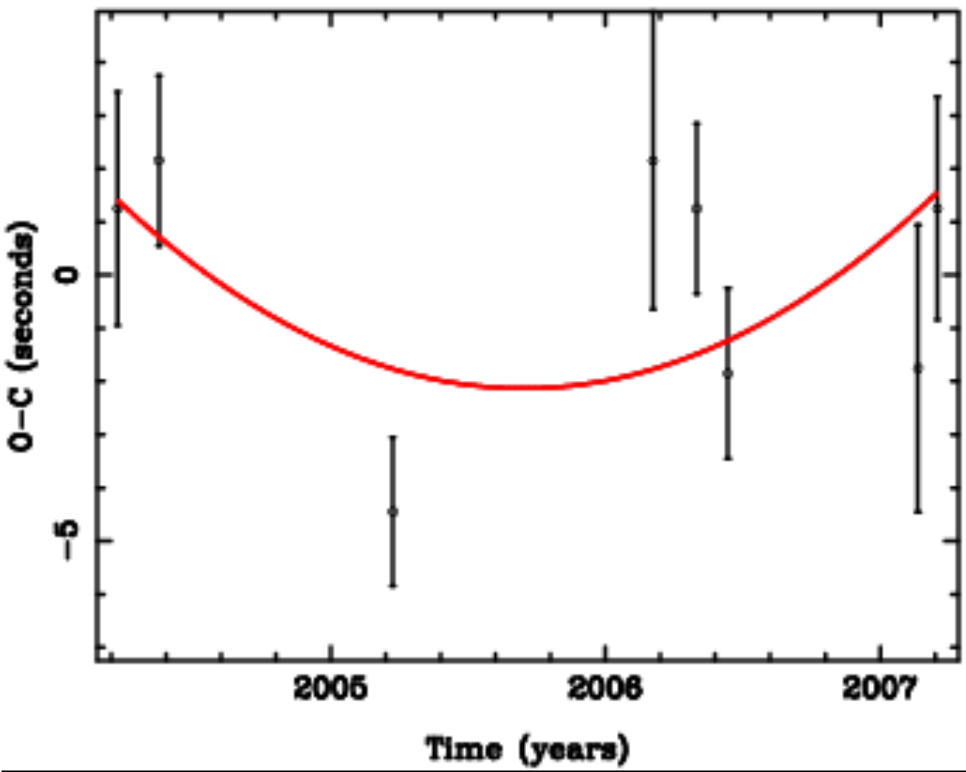
WD1354+0108 Mullally 2008

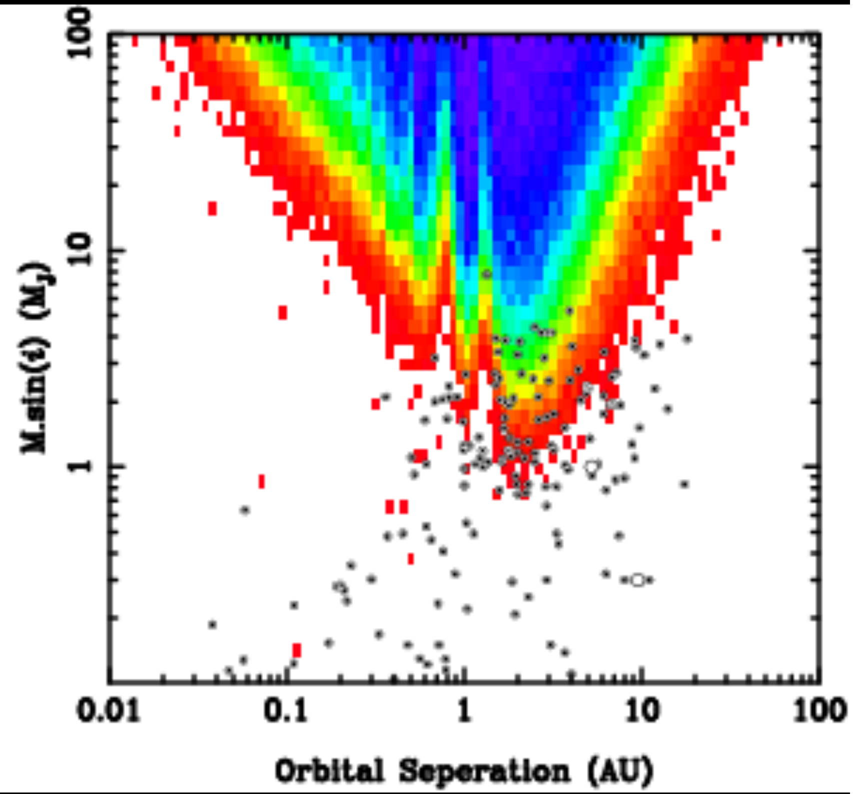




Results

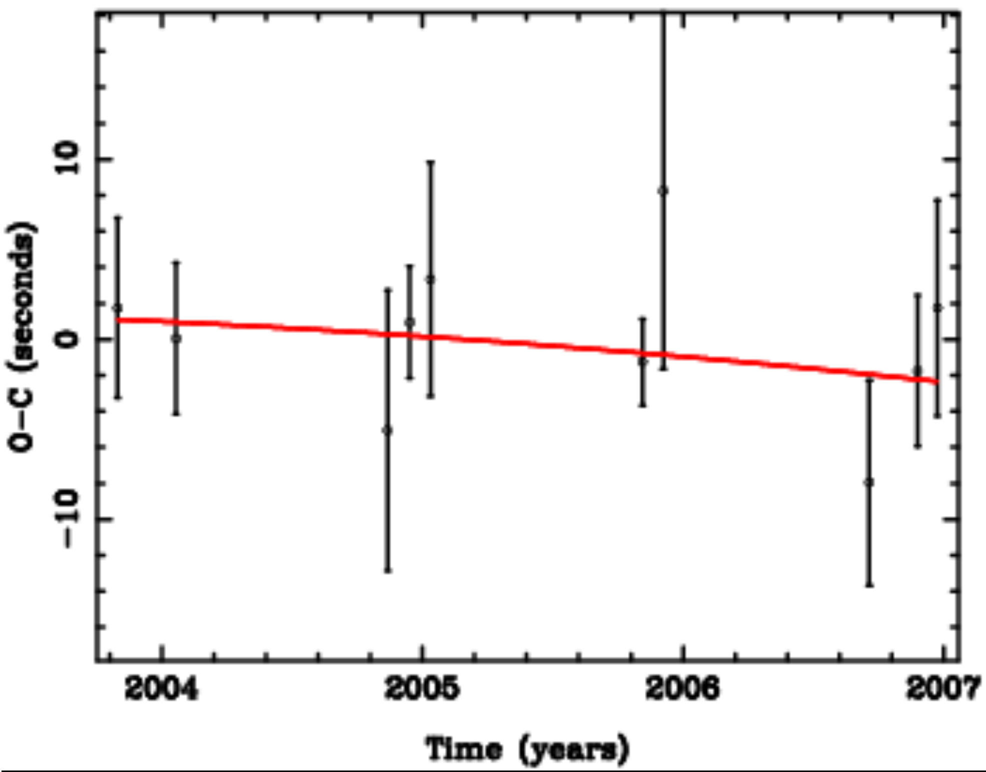
WD1355+5454

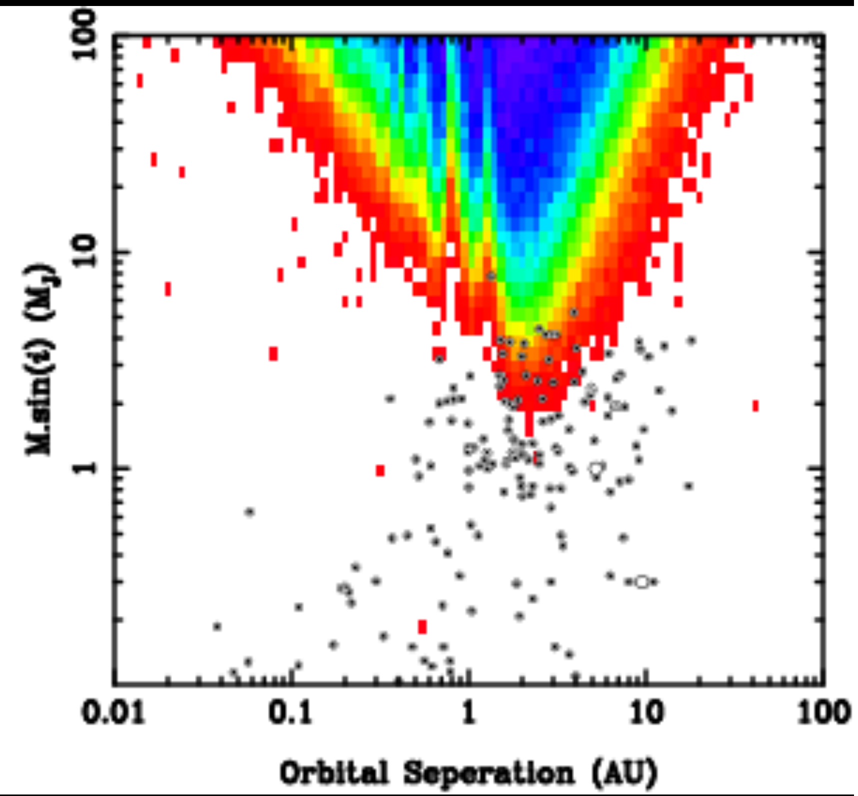




Results

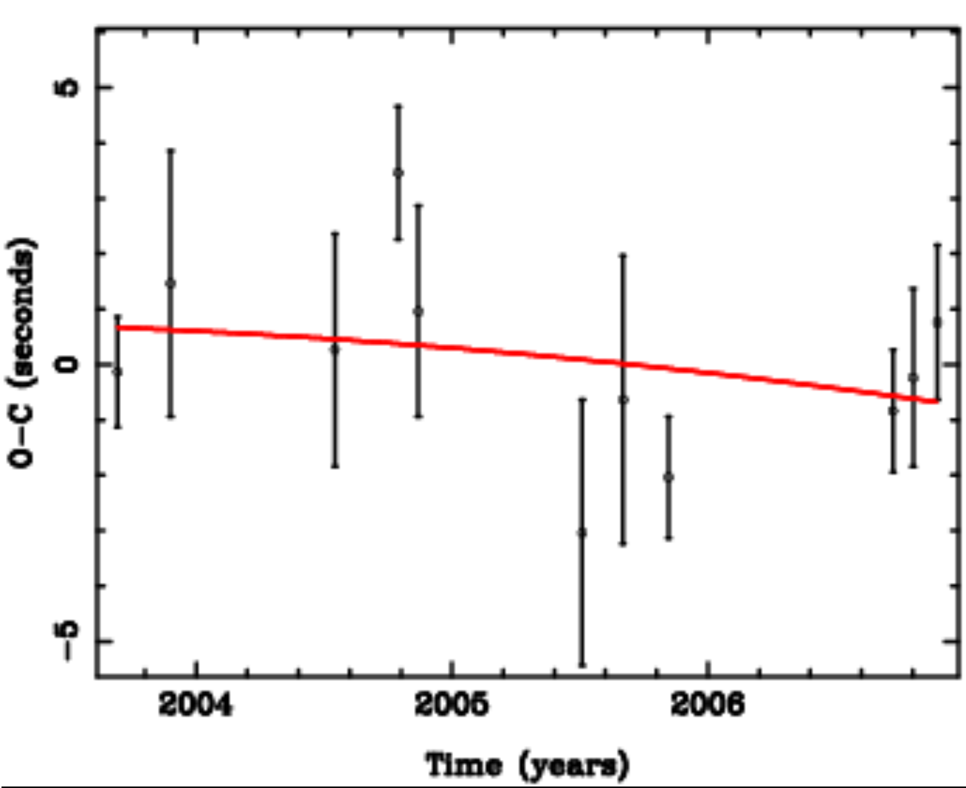
WD0214-0823

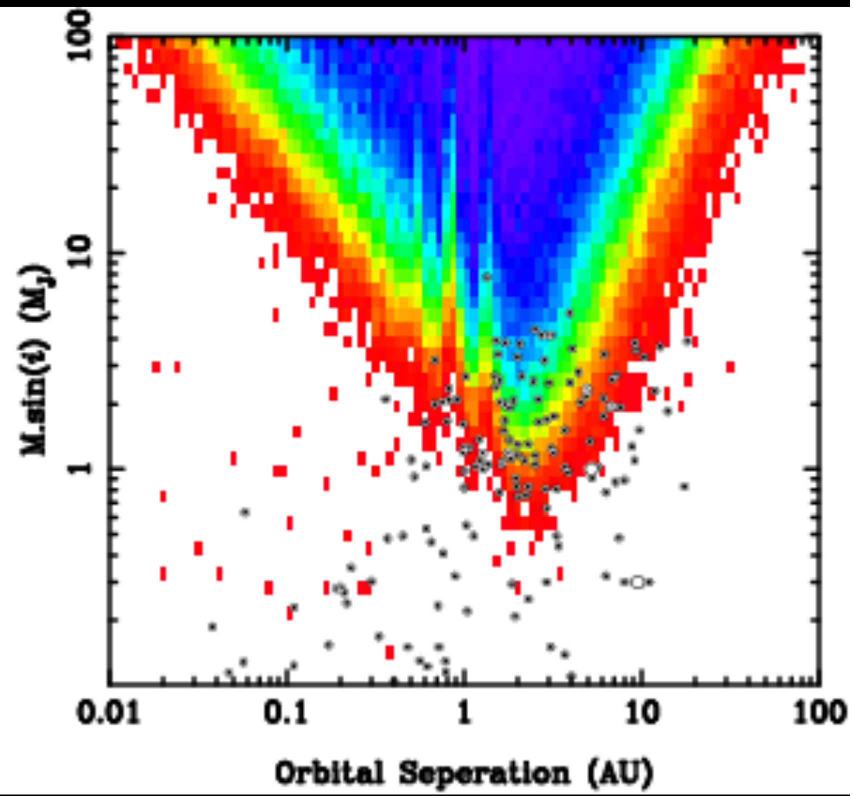




Results

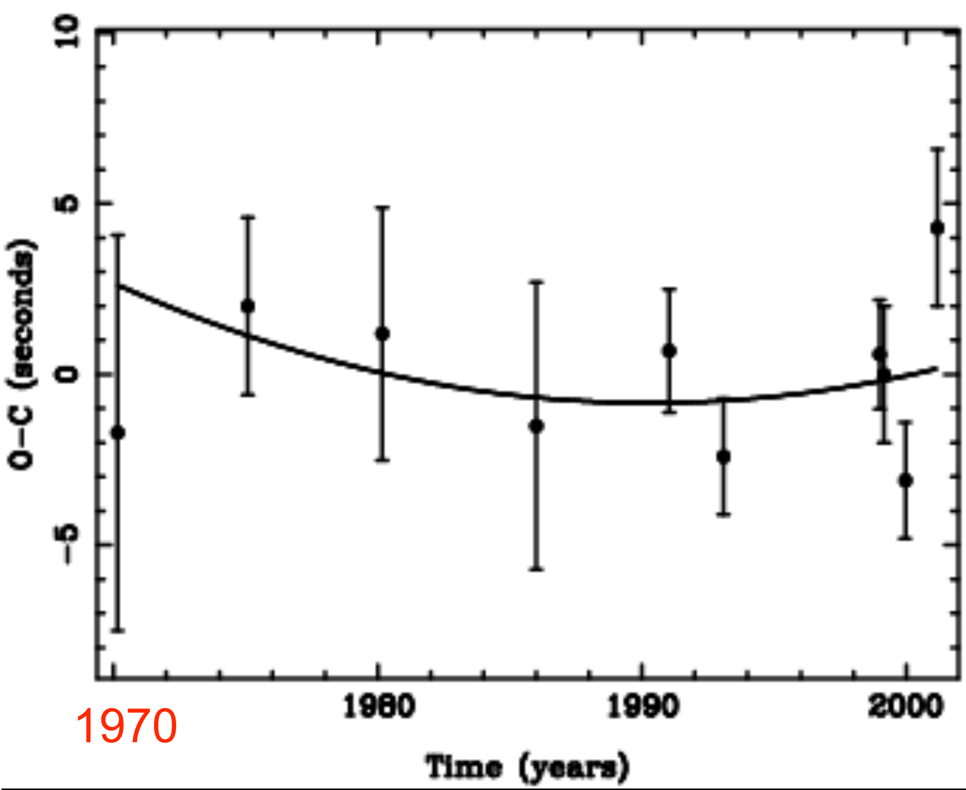
WD2214-0025

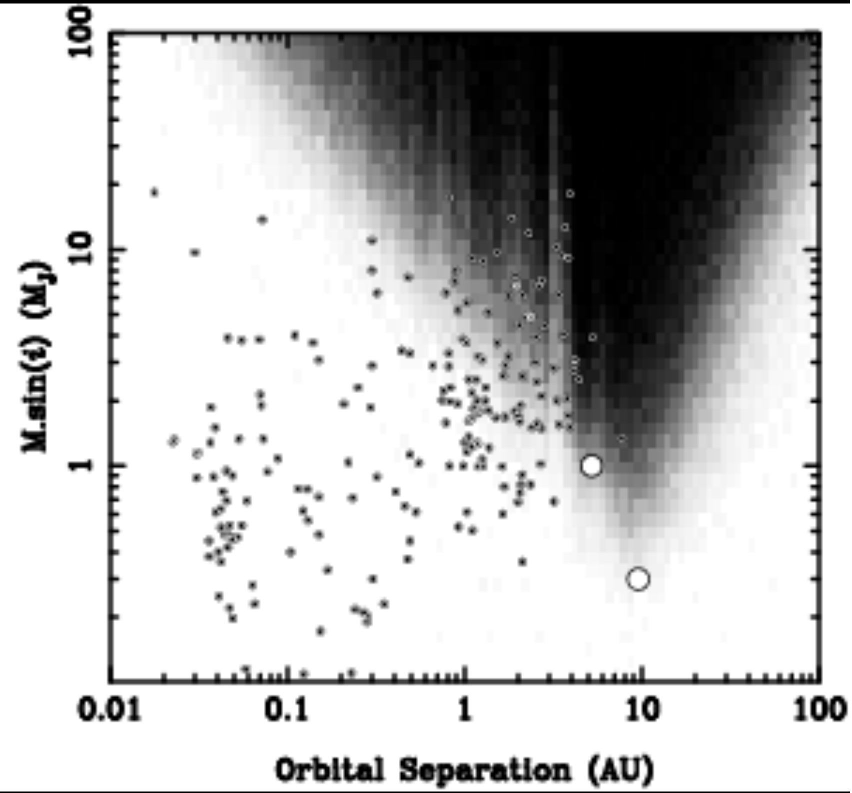




Results

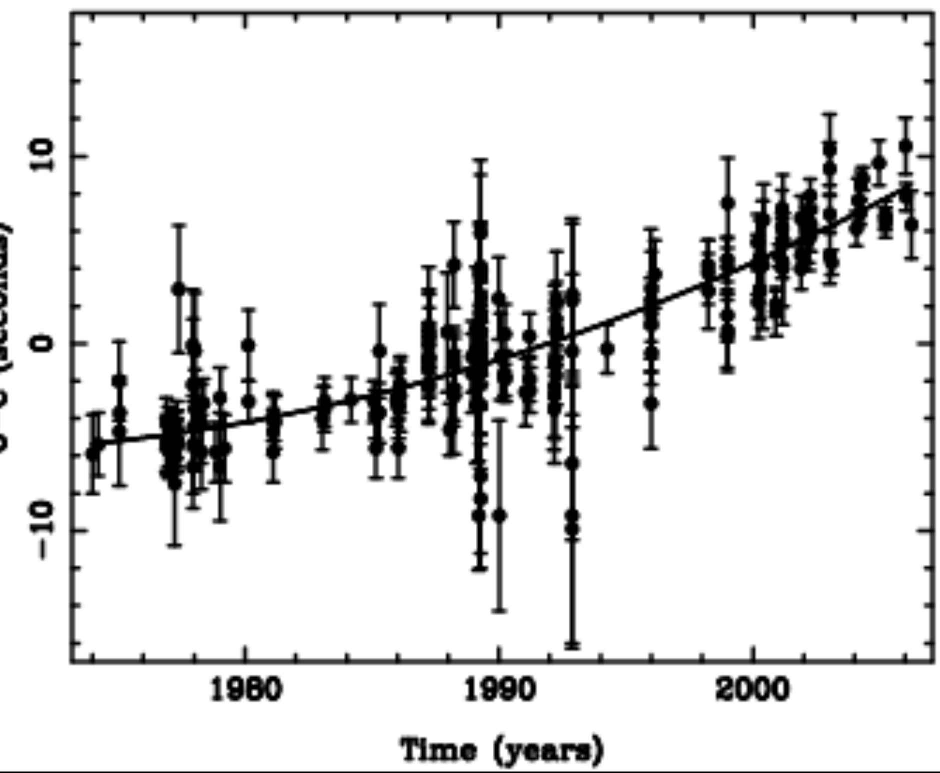
R548

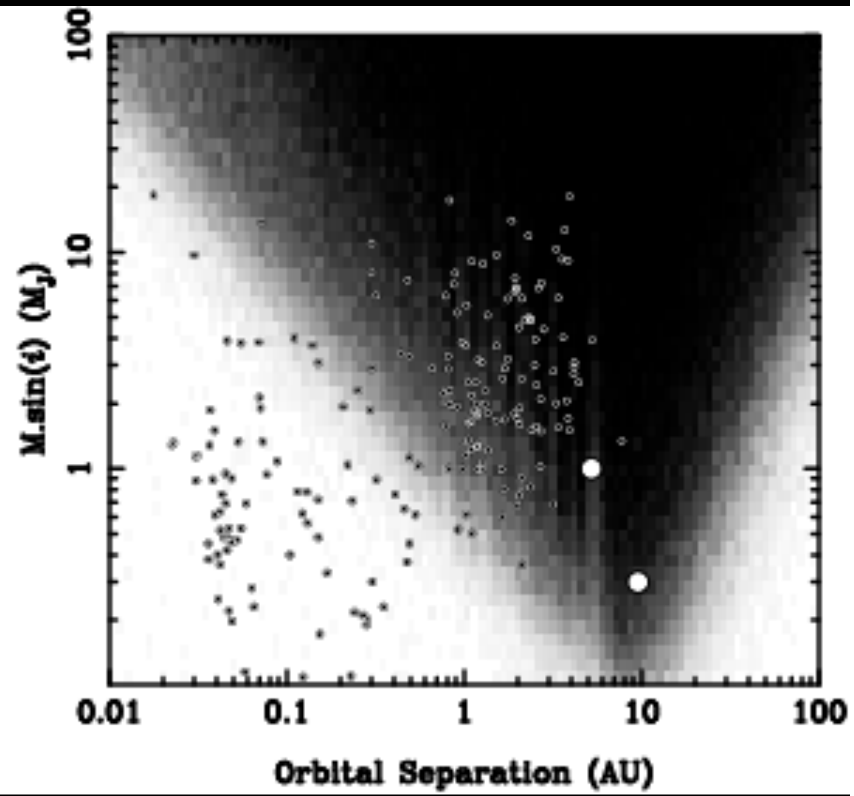




Results

G117-B15A

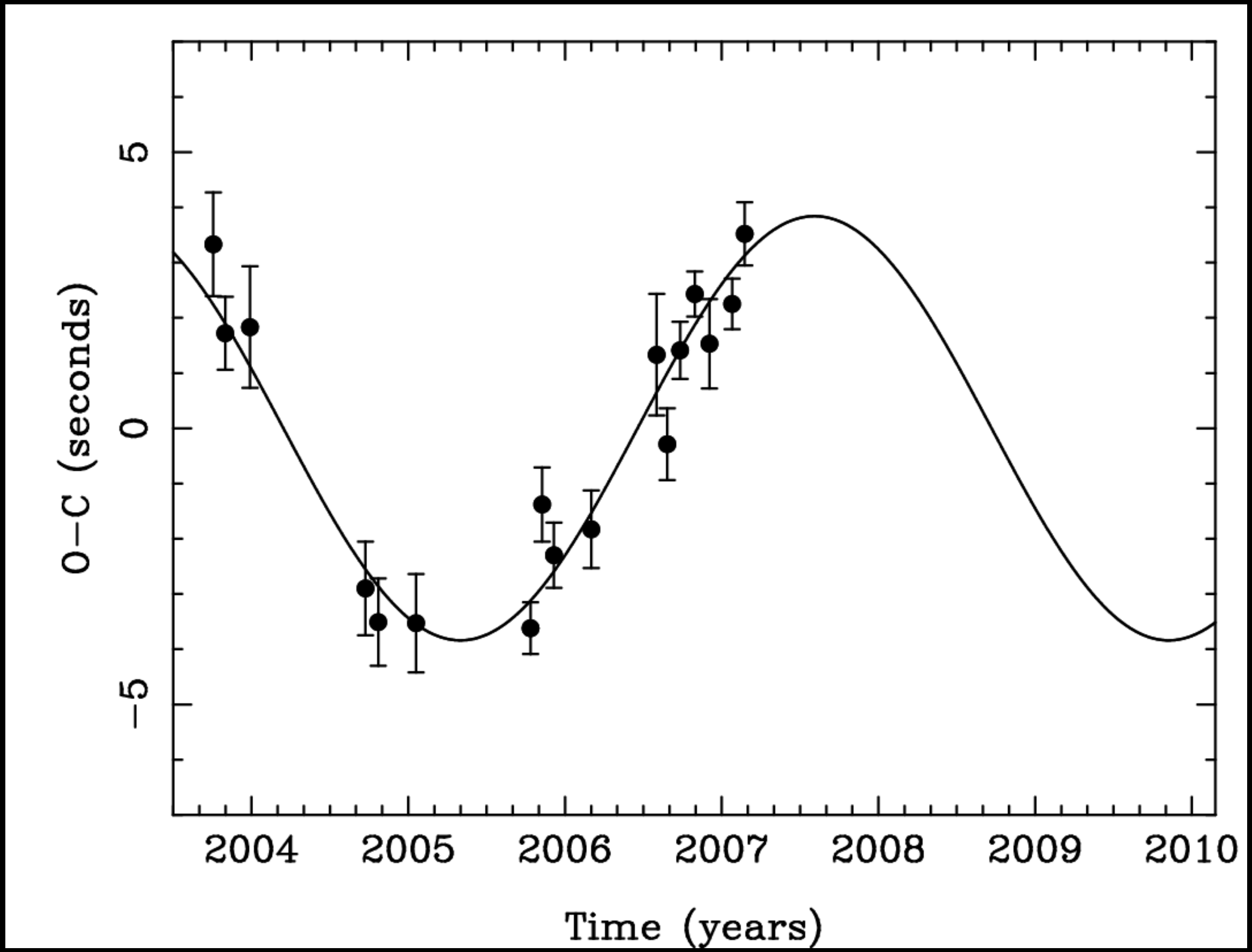




A Promising Candidate

GD66 as of July 2007

Pulsations later than expected



Pulsations earlier than expected

What else could it be?

Cooling of the star?

Cooling of the star produces a parabola in the O-C diagram

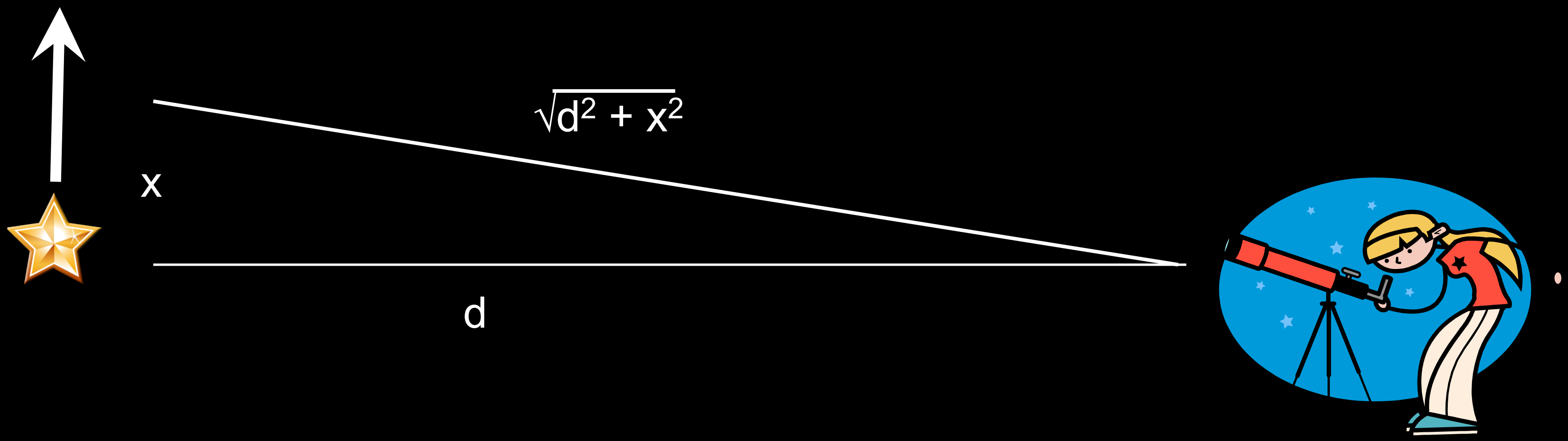
Effect of cooling predicted, and observed to be $\sim 10^{-15}$ in another DAV, G117-B15A, but 10^{-12} in GD66

Cooling rate is dependent on average atomic weight of core

Average atomic w$\dot{P}$ght of core must be $\approx$ 5900 to explain such a high

What else could it be?

Proper motion?



Proper motion produces a parabolic change in distance to the star and therefore a parabola in the O-C diagram

Proper motion is a smaller effect even than cooling

- μ= 133 mas/yr
- $\dot{P}_{pm} = 2.430 \times 10^{-18} P \mu^2 d,$

Pajdosz (1995)

- P=302s d≈ 50pc
- $\dot{P}_{pm}$= 6.5 x 10^{-16}
- $\dot{P}_{obs}$ ~ 10^{-12}

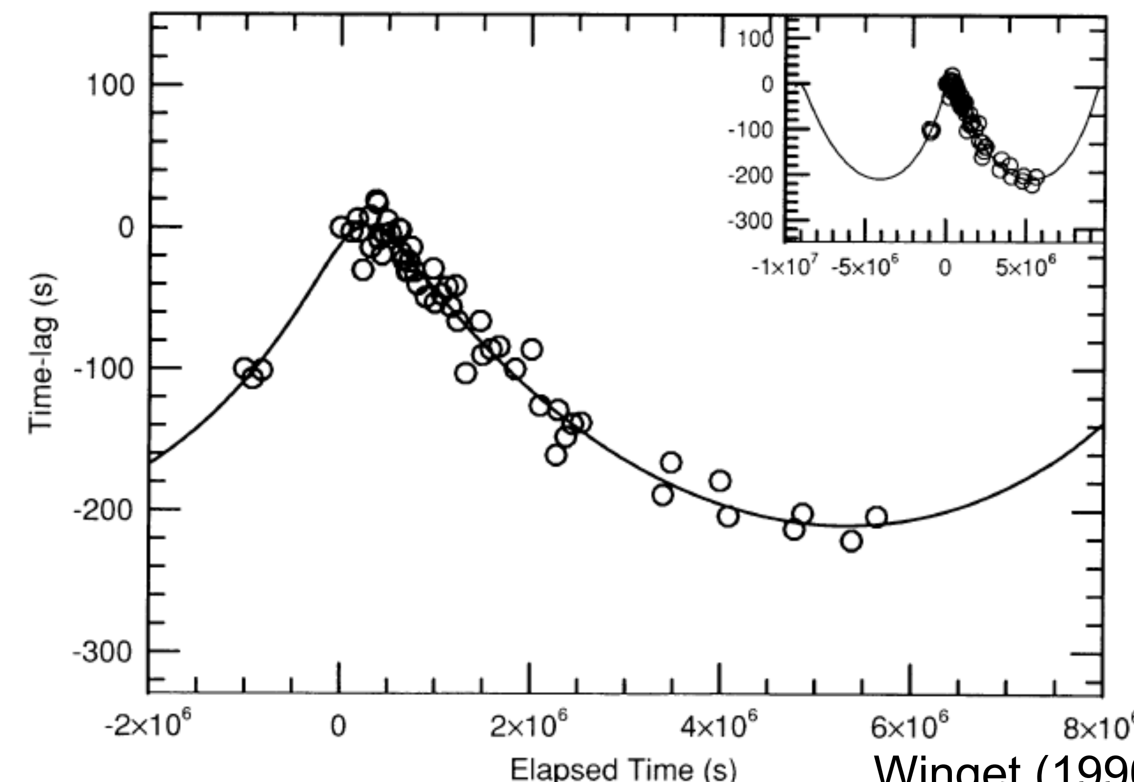
$\dot{P}$ $\dot{P}$ $\dot{P}$

GD66

No known effect can explain observed O-C diagram for GD66

Of course, there’s always the unknown...

G29-38: A DAV that seemed to have a companion...

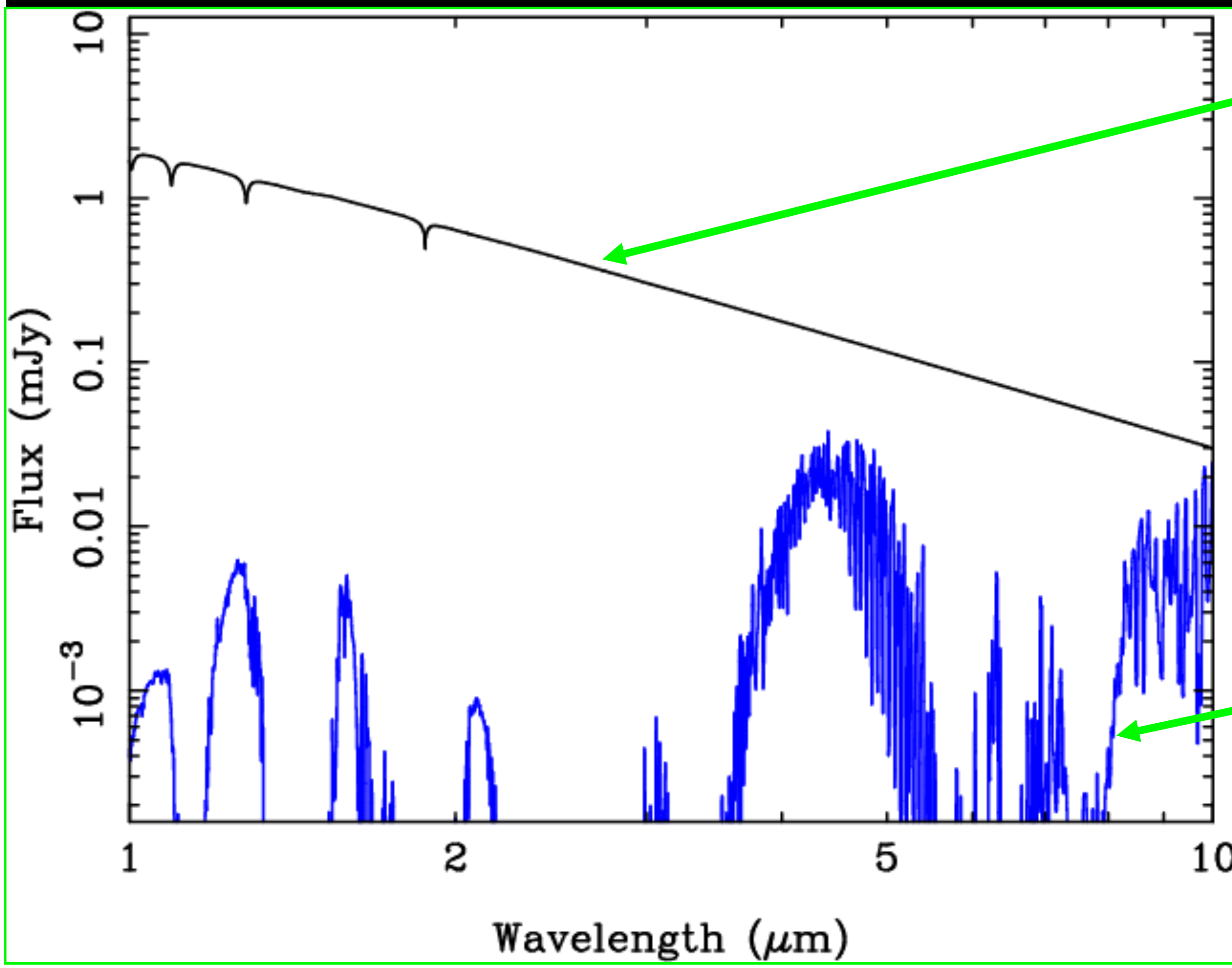


Winget (1990)

(but doesn't)

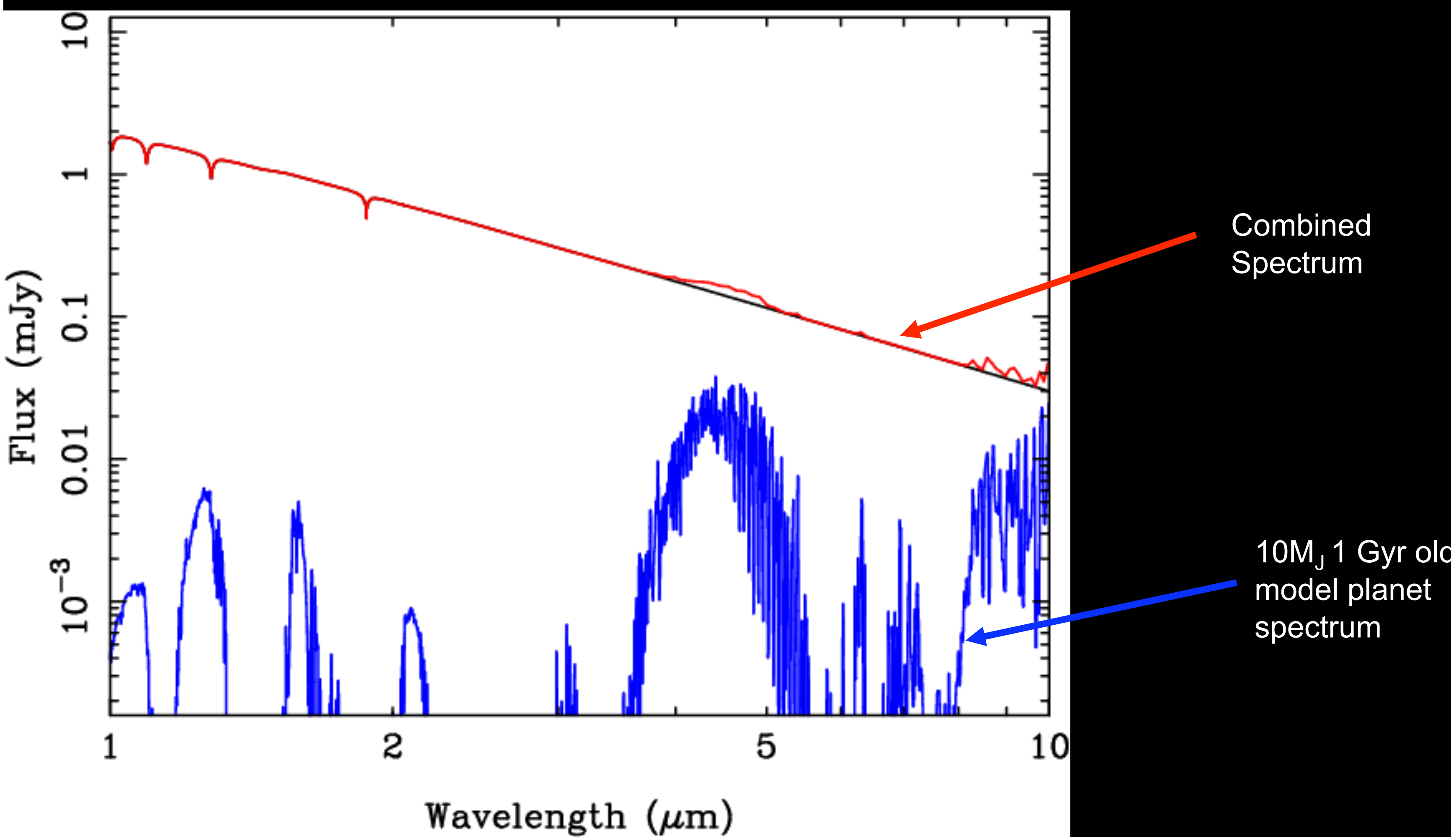
Seeing is believing

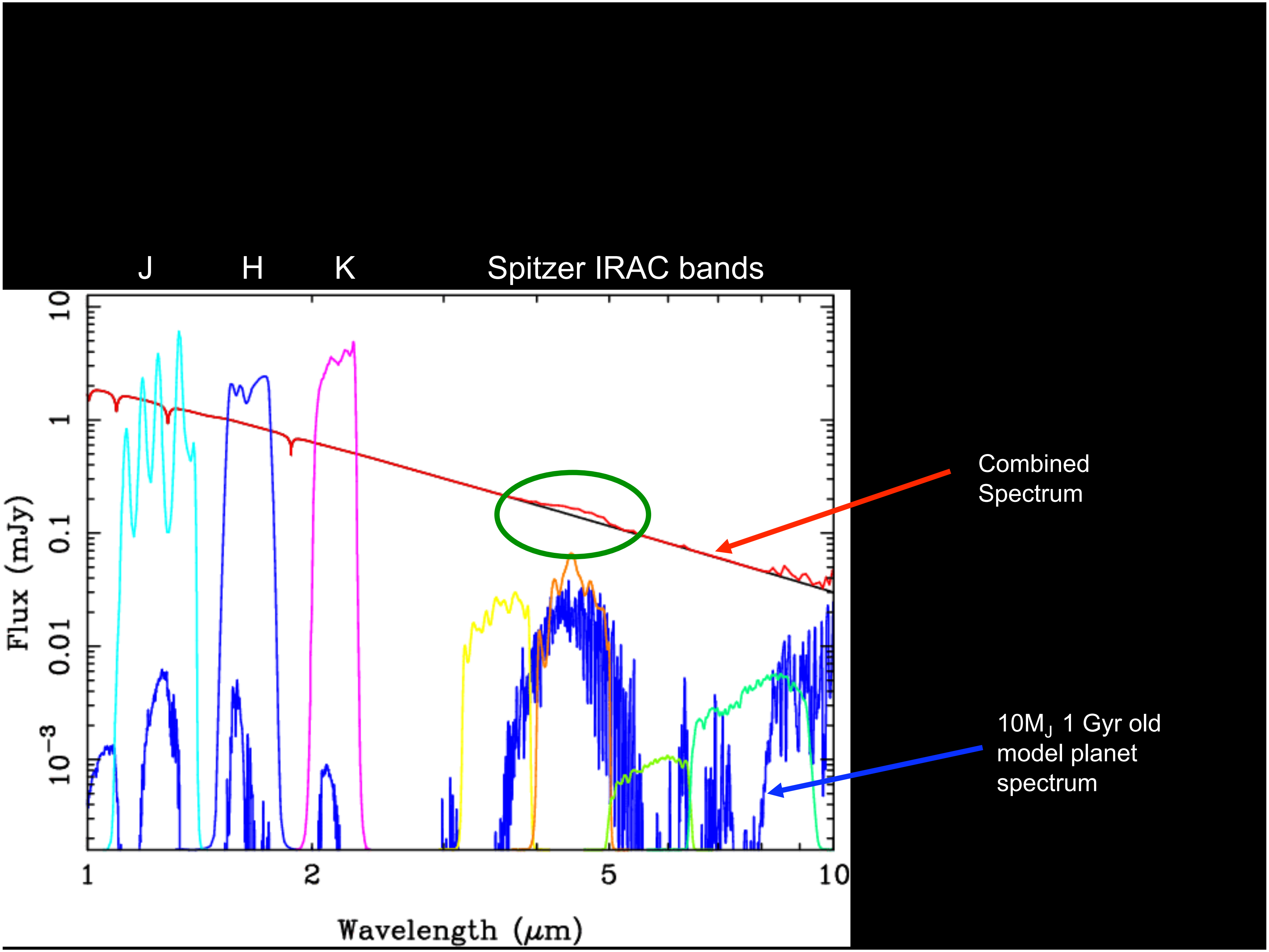
Confirmation through direct detection with *Spitzer*



12,000 K DA White Dwarf model spectrum

$10M_J$ 1 Gyr old model planet spectrum


Flux (mJy)
10
1
0.1
0.01
10^{-3}
1
2
5
10
Wavelength (μm)
Combined Spectrum
$10M_J$ 1 Gyr old model planet spectrum



J
H
K
Spitzer IRAC bands
Flux (mJy)
10
1
0.1
0.01
10^{-3}
1
2
5
10
Wavelength (μm)
Combined Spectrum
$10M_J$ 1 Gyr old model planet spectrum

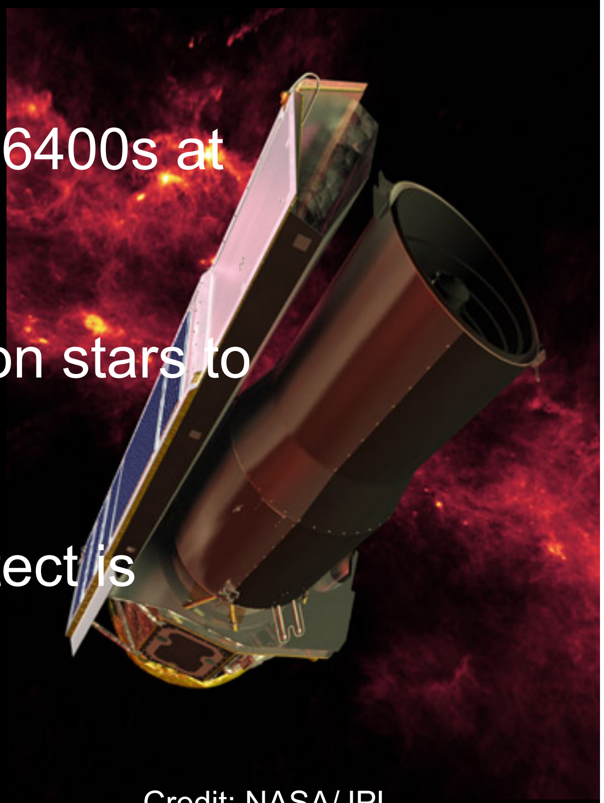
The Plan

If the planet is bright enough, we can detect it as an excess flux at 4.5μm relative to 3.8μm using IRAC on *Spitzer.*

We observed GD66 for 1600s at 3.8μm and 6400s at 4.5μm

We observed ZZ Ceti and L19-2 as calibration stars to determine the expected flux ratio

Limit on the least massive planet we can detect is set by the systematic uncertainty in IRAC.



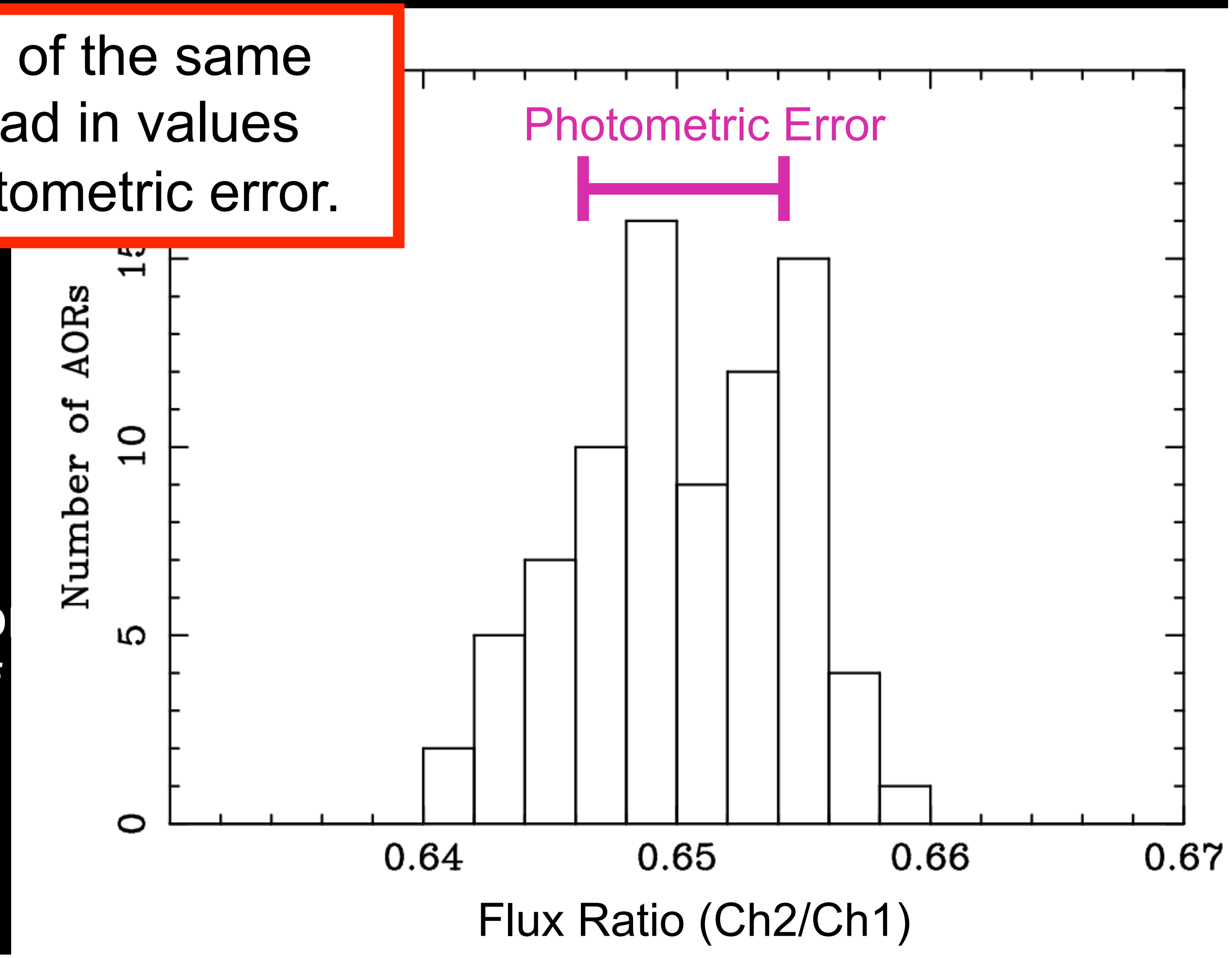
Credit: NASA/JPL-Caltech

Detection Limit

is set by our systematic uncertainty

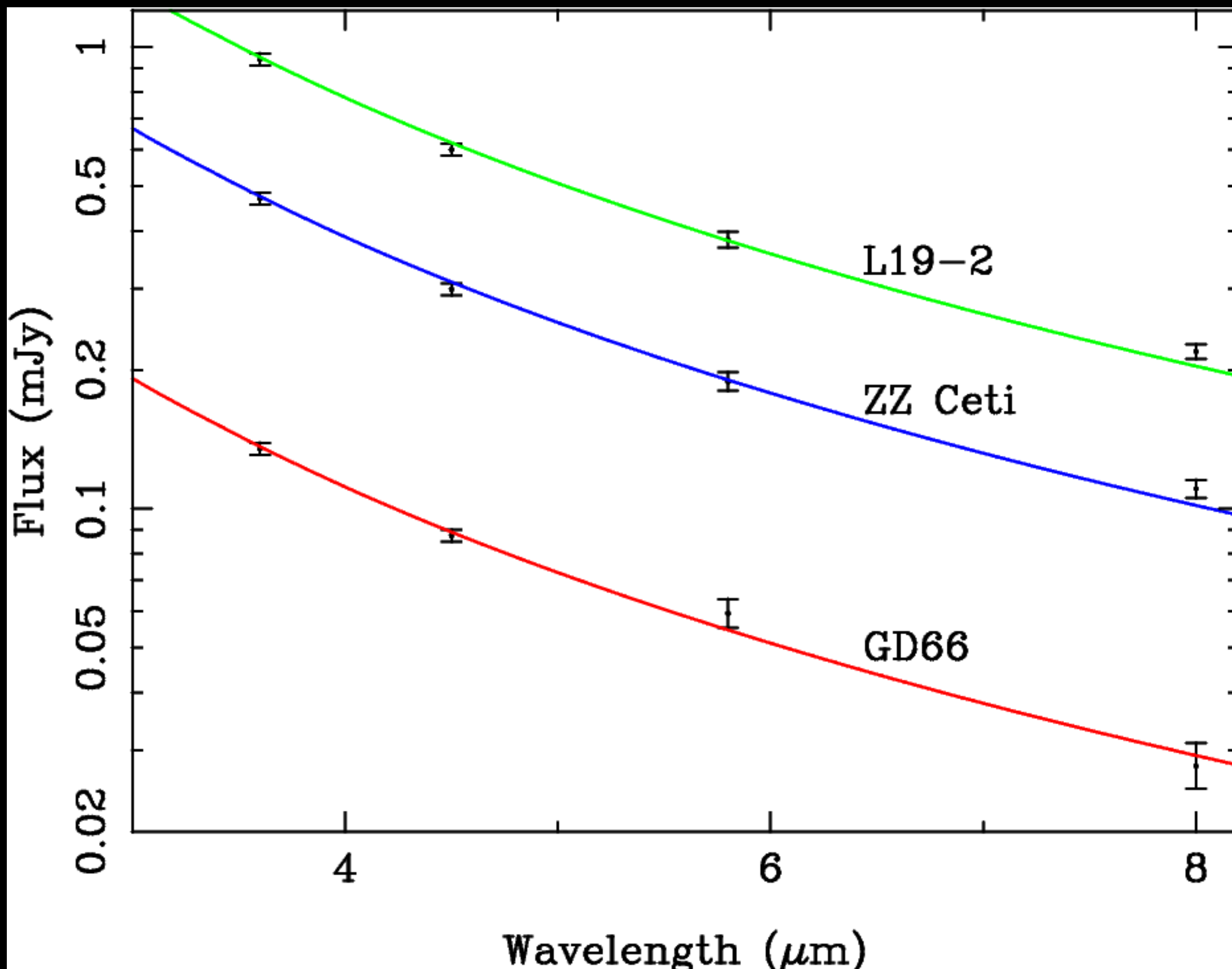
BD +60 1753

Repeat observations of the same star produces a spread in values greater than the photometric error.

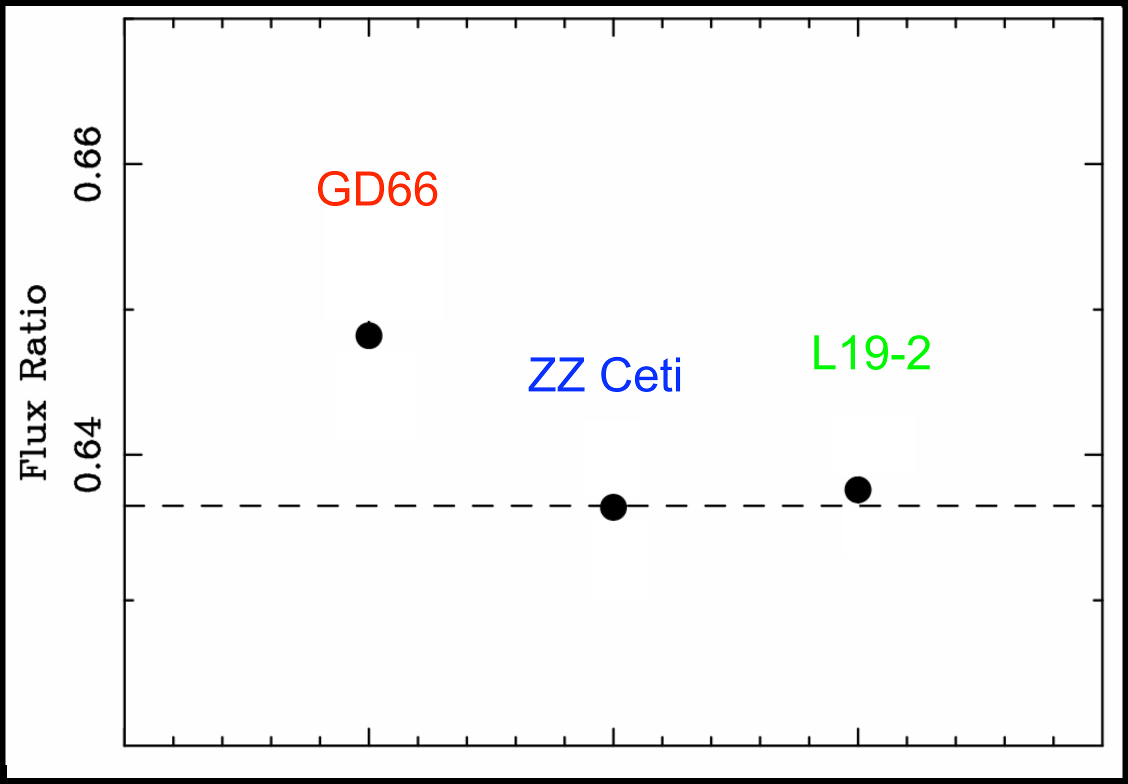


This places a detectio limit on any excess of 0.54%

Result



Result



There does seem to be an slight excess, but it's only 1.7σ signifcant

Upper limit on companion mass

requires an estimate of age

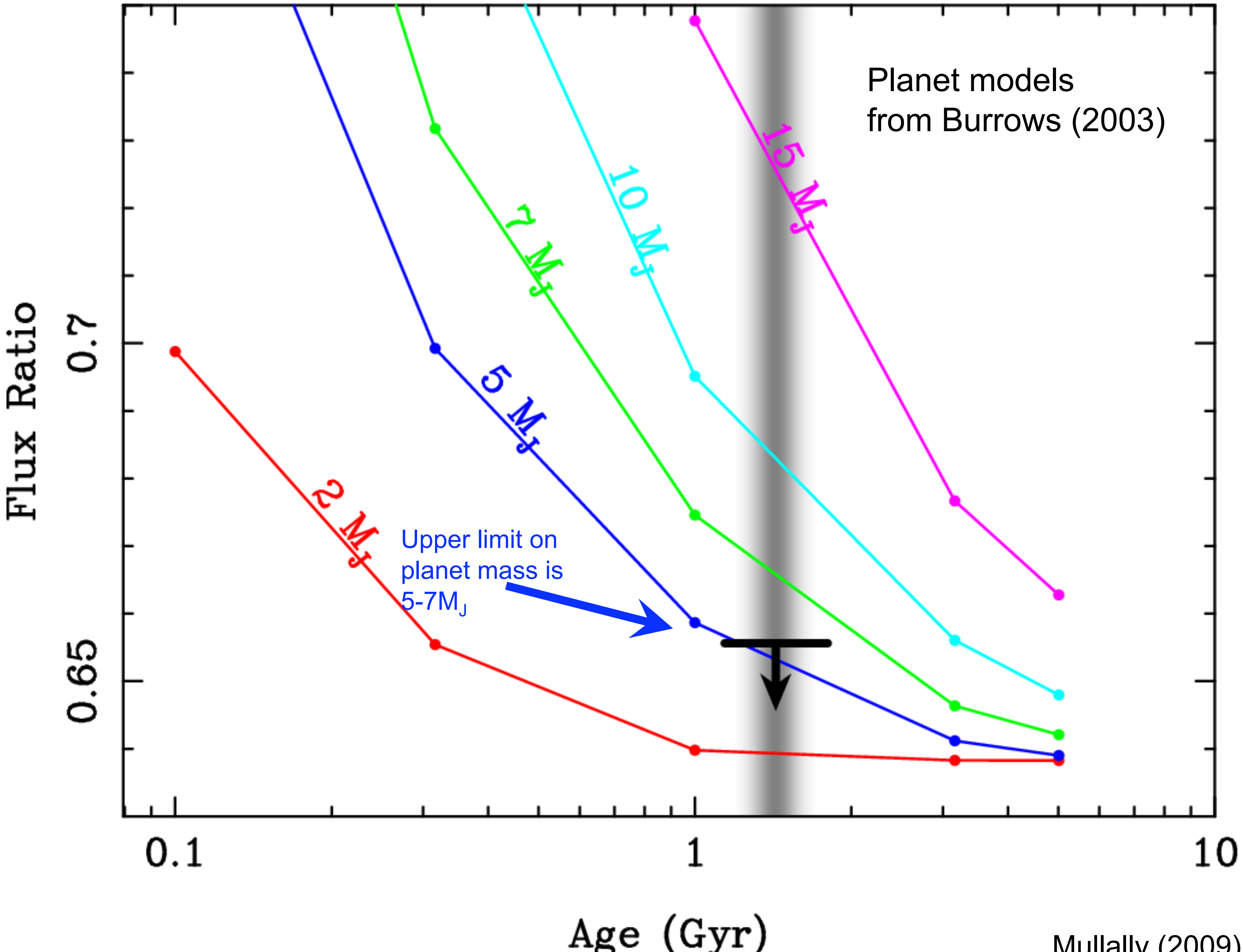
T_{eff} = 11,989 K Bergeron (2004)
log(g)=8.05

⇒Mass = 0.64 $M_\odot$ Wood (1992)
Cooling Time = 500 Myr

⇒Main-sequence Mass = 2.26--2.64 $M_\odot$ Kalirai (2007), Dobbie (2006), Meng (2007)

Total Age: 1.2--1.6 Gyr

Main-sequence Age = 700--1100 Myr Pols (1998)



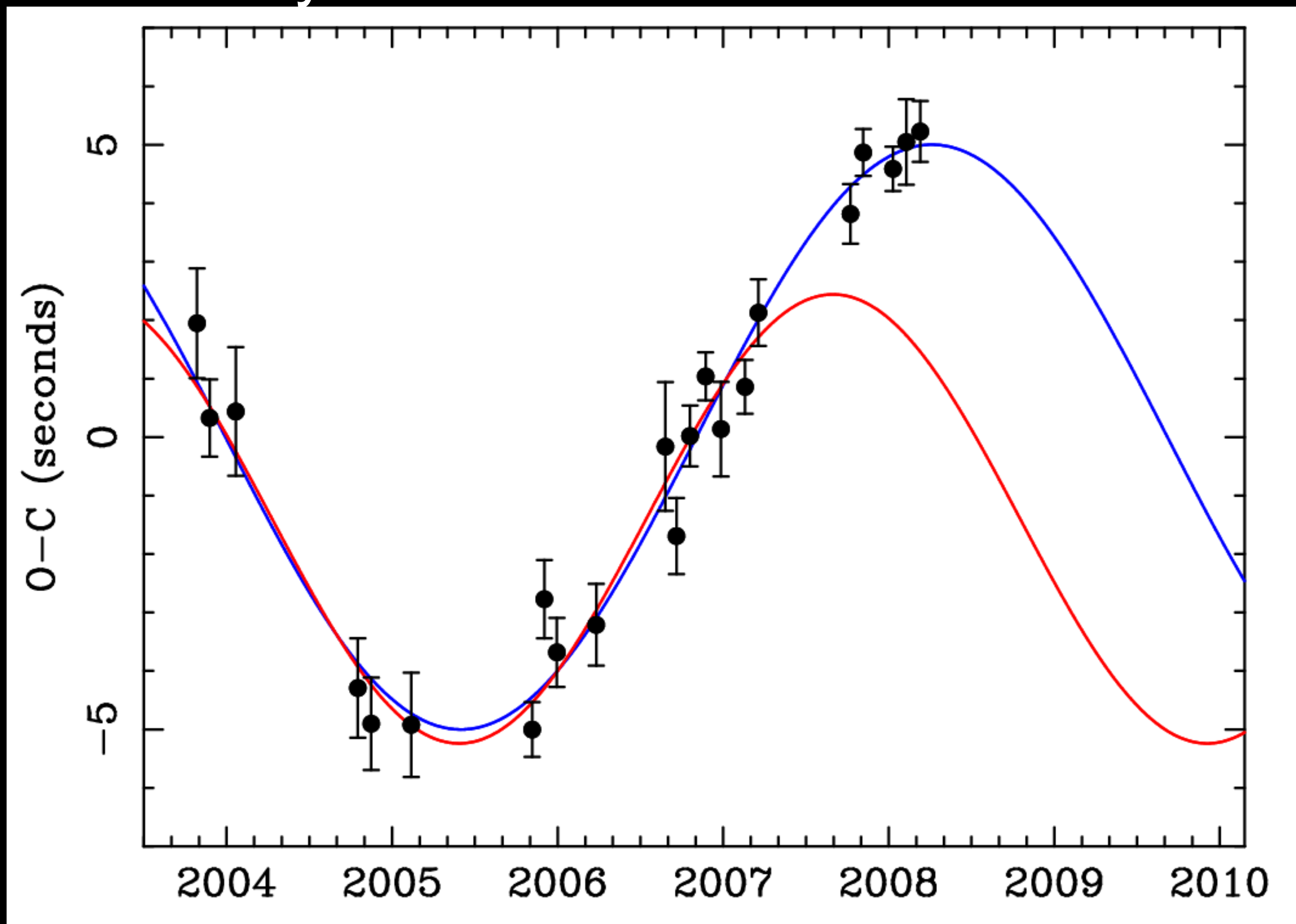
Mullally (2009)

So, Spitzer observations didn't see anything conclusive

But additional ground based observations will soon cover an entire orbit, right?

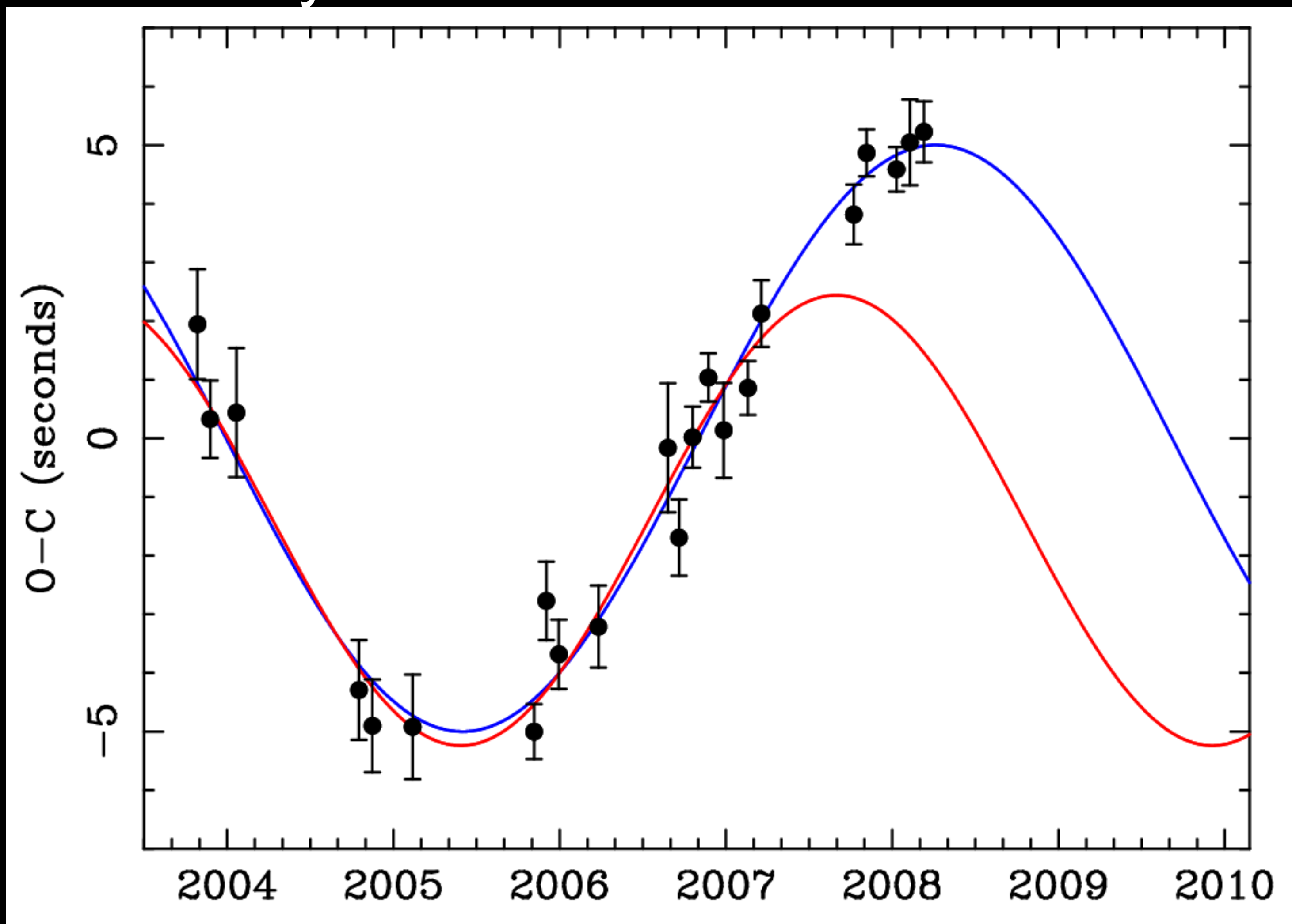
More ground based observations

GD66 as of July 2007 2008

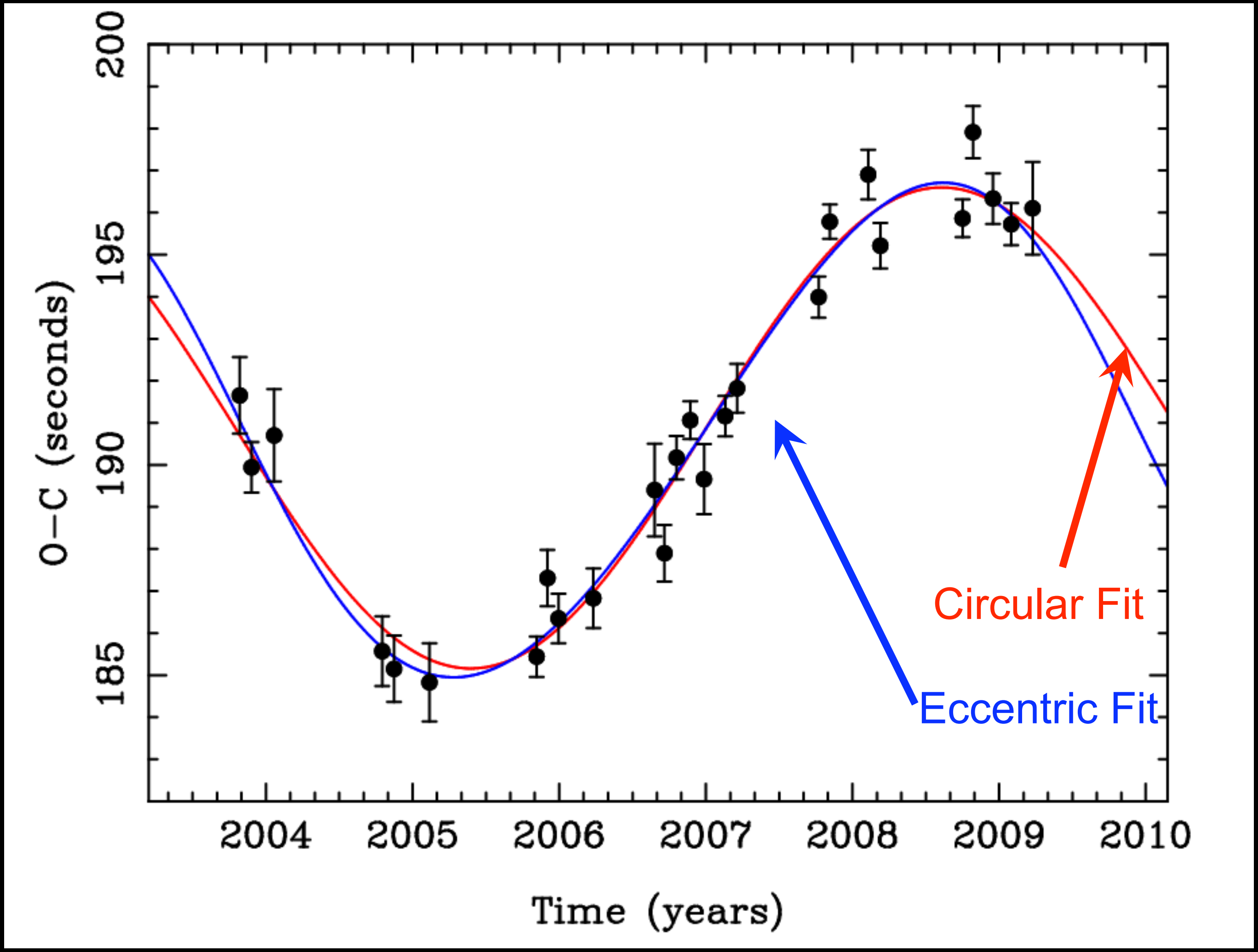


More ground based observations

GD66 as of July 2008

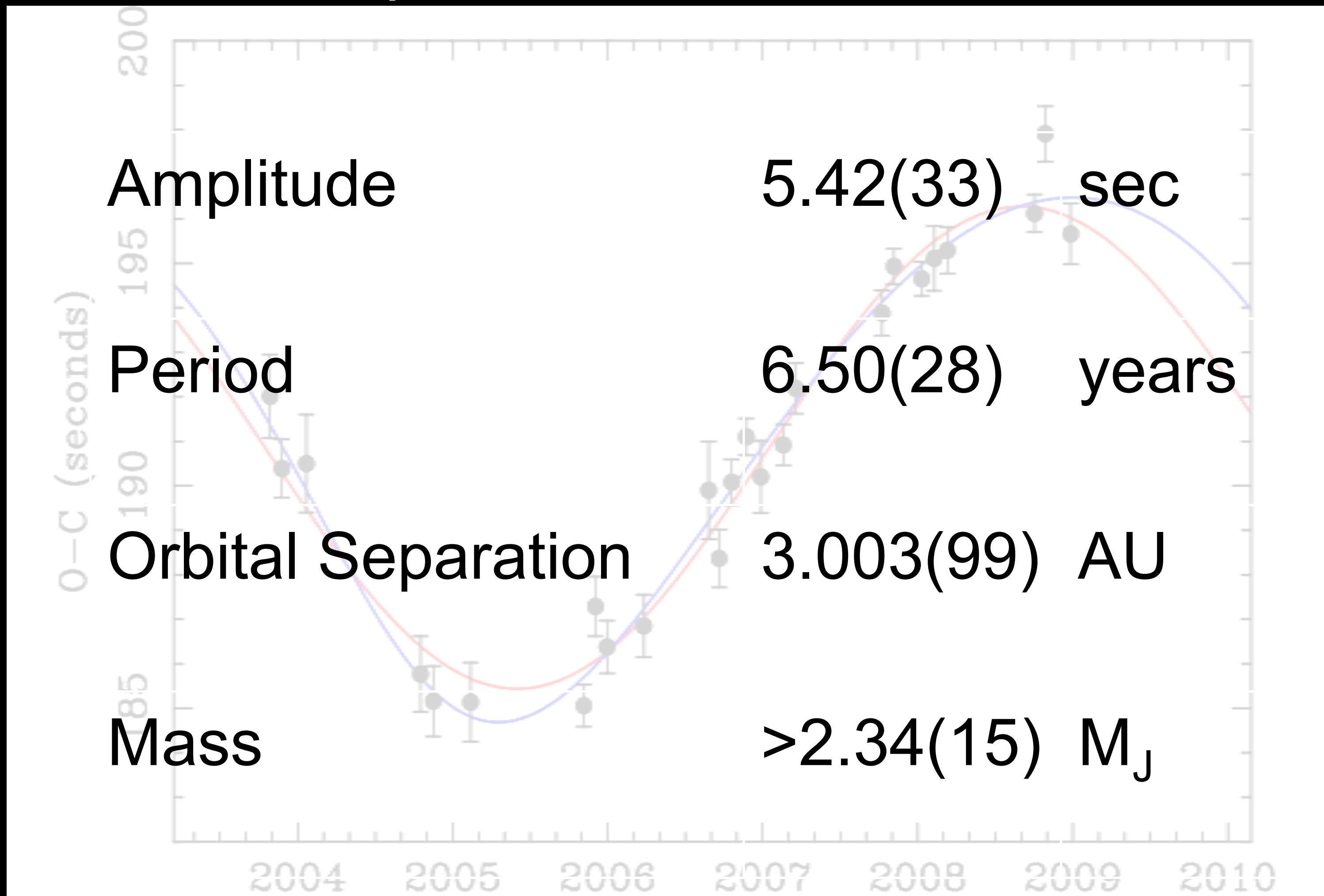


Most recent observations



More ground based observations

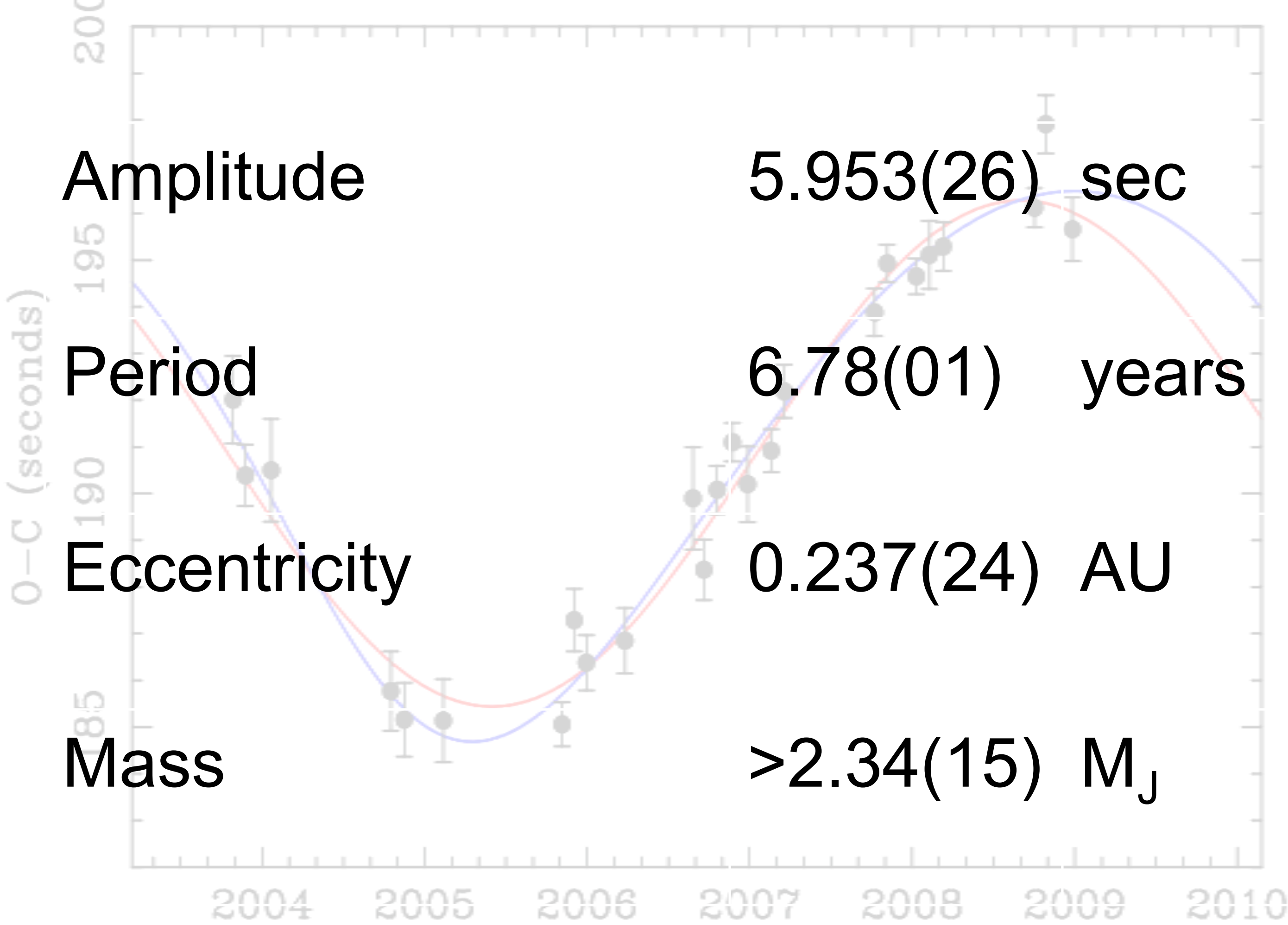
Current best fit parameters



Amplitude	5.42(33)	sec
Period	6.50(28)	years
Orbital Separation	3.003(99)	AU
Mass	>2.34(15)	M_J

More ground based observations

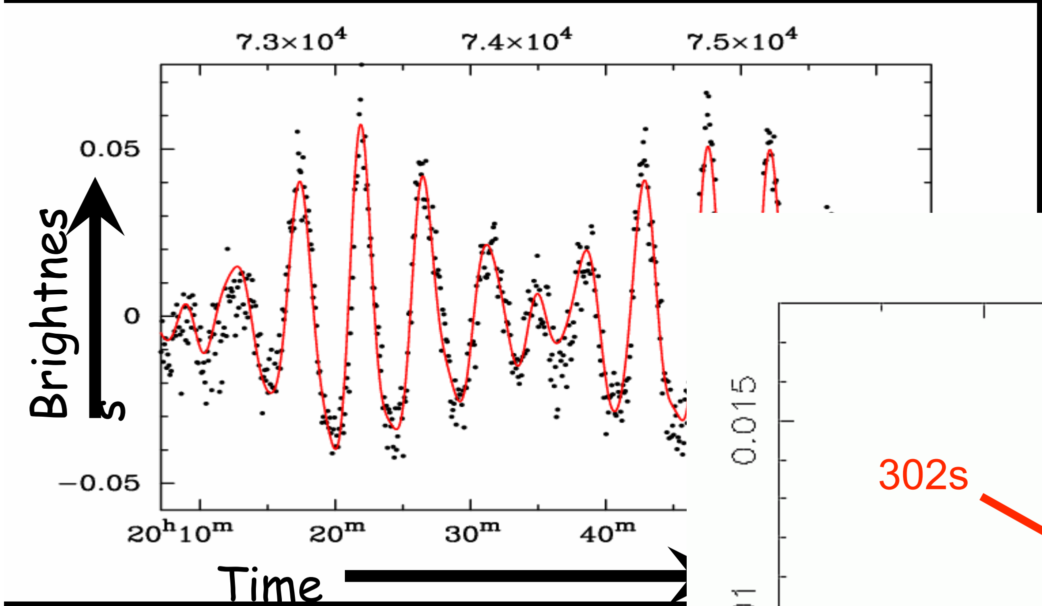
Current best fit parameters to eccentric fit

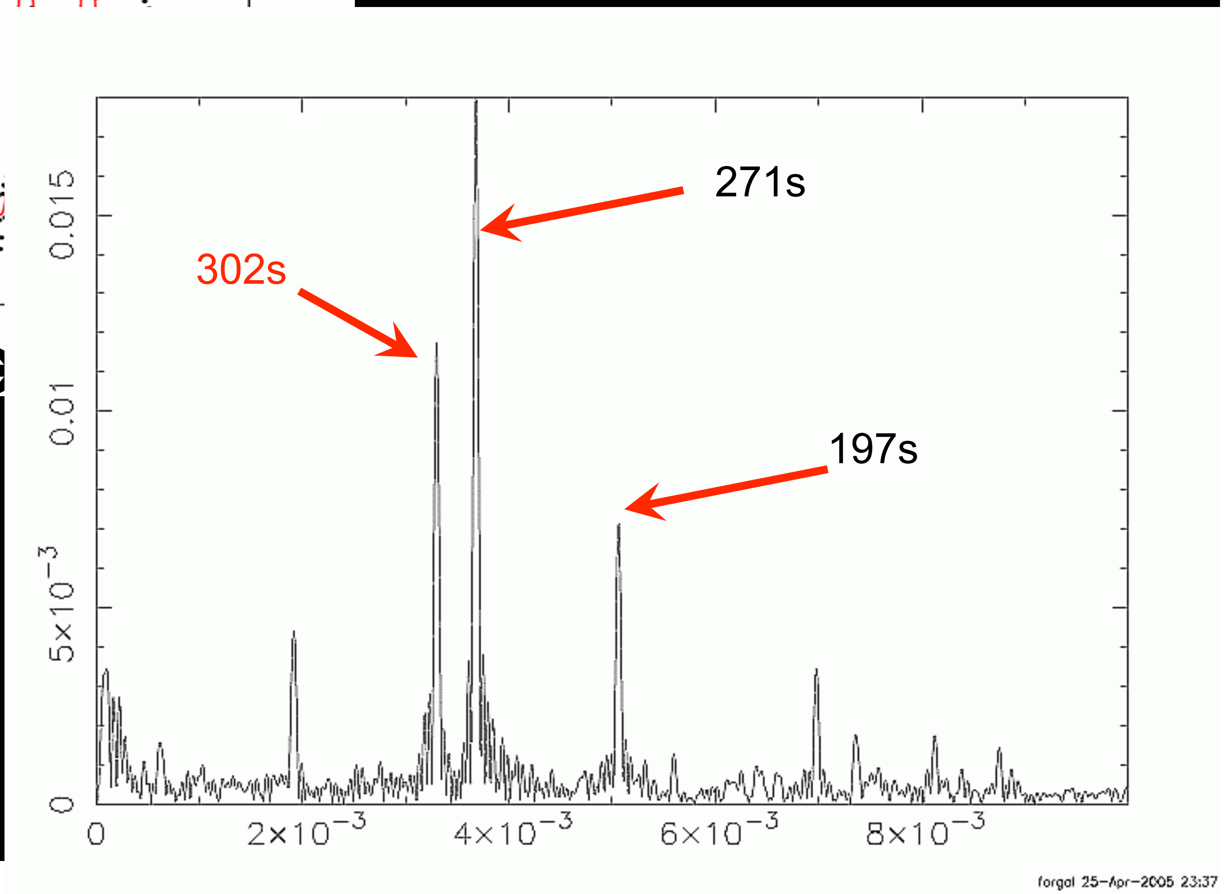


Amplitude	5.953(26)	sec
Period	6.78(01)	years
Eccentricity	0.237(24)	AU
Mass	>2.34(15)	M_J

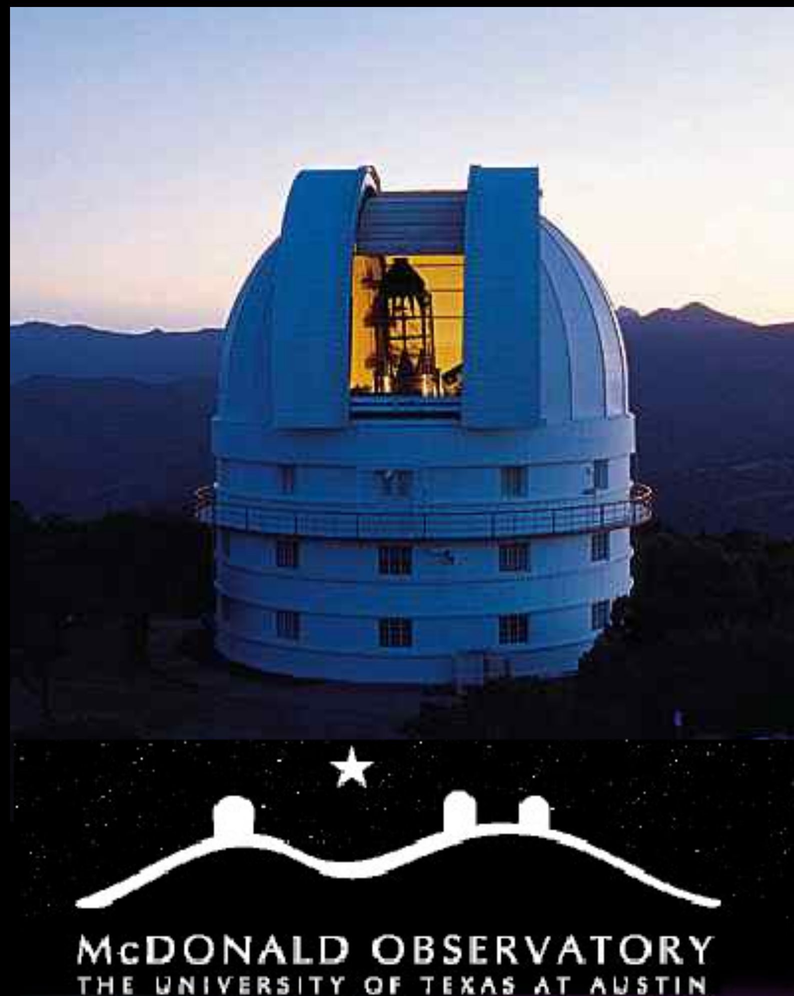
Future work

Confirmation from an independent pulsation period





The End.



Title

Subtitle

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