Planets Around White Dwarf Stars

Fergal Mullally,

Don Winget, S. O. Kepler,

Ted vonHippel et al

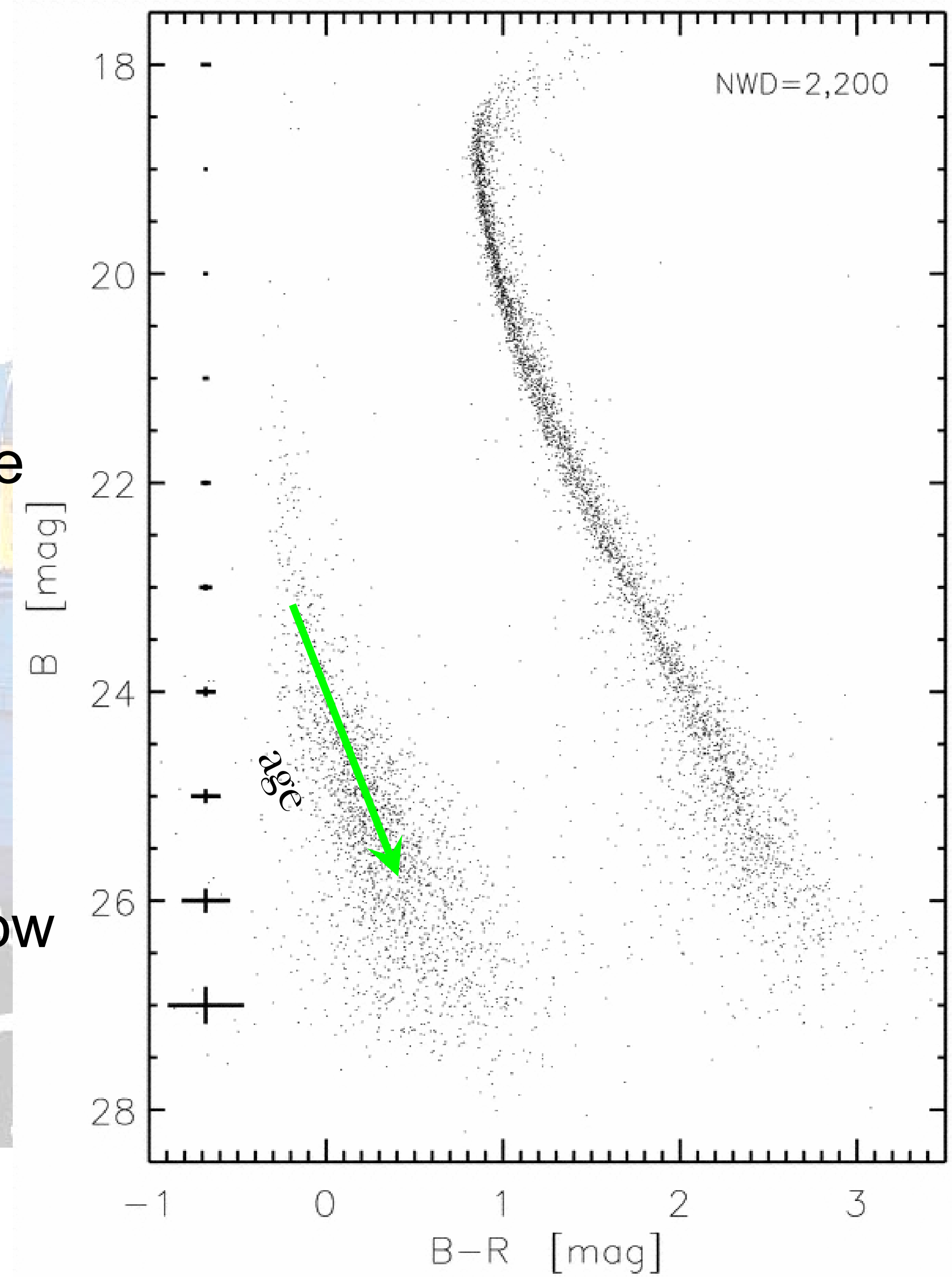
Introduction to White Dwarves

- The final evolutionary state for nearly all stars (≈98%)

•Radius ≈1$R_\oplus$ Mass ≈0.6$M_\odot$

•No more energy sources.

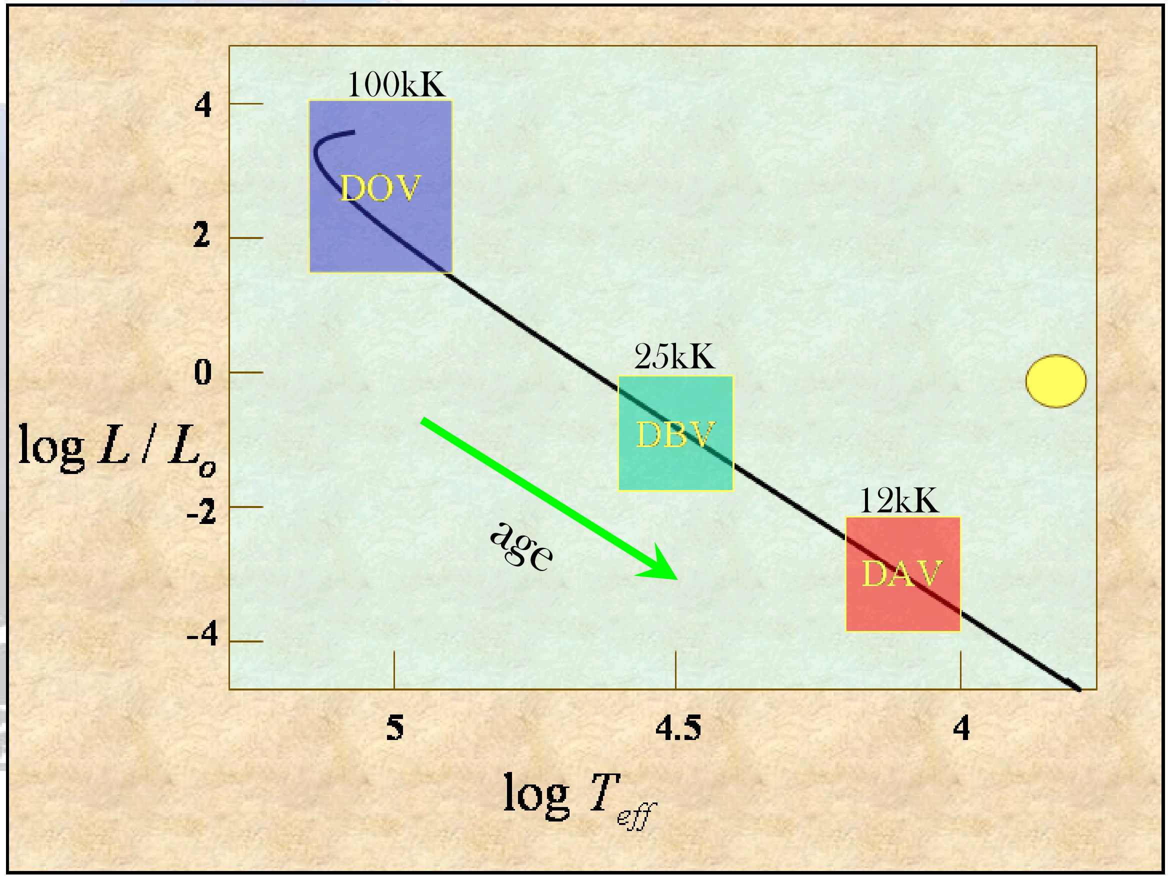
•As they grow older, they grow colder, and fainter



Monelli et al. (2005), ApJL 621,117

Variable White Dwarves

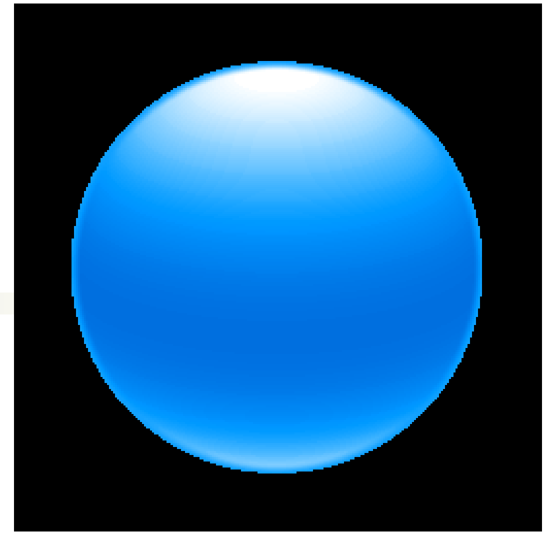
- As they cool WDs become variable stars
- This occurs in 3 different temperature regions.



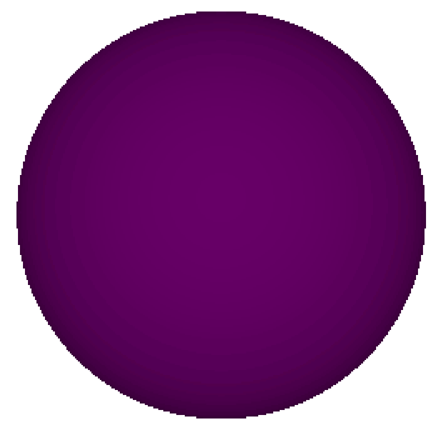
Variable White Dwarves

High Gravity means pulsations are *non-radial.*

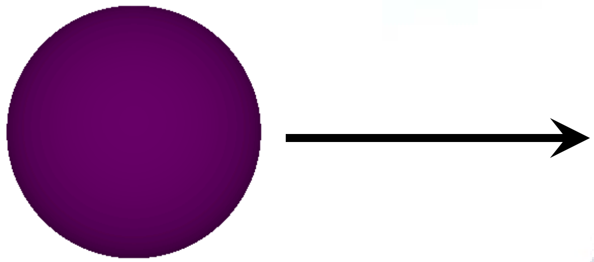
Multi-periodic pulsations 100-1000s, exact mechanism poorly understood

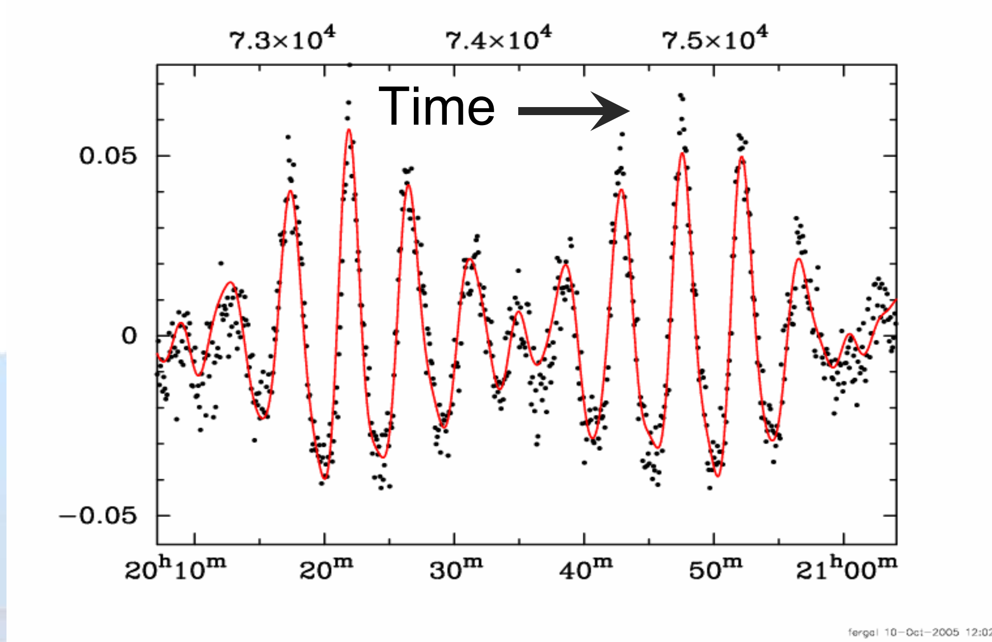


$\ell=2$

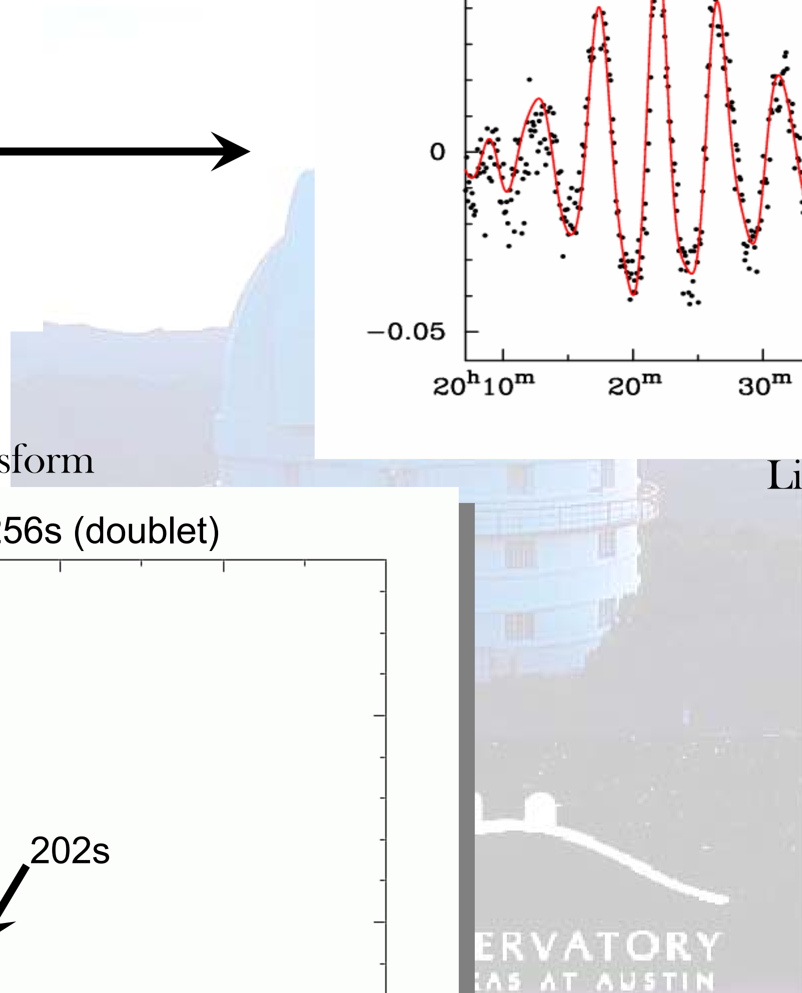


$\ell=4$

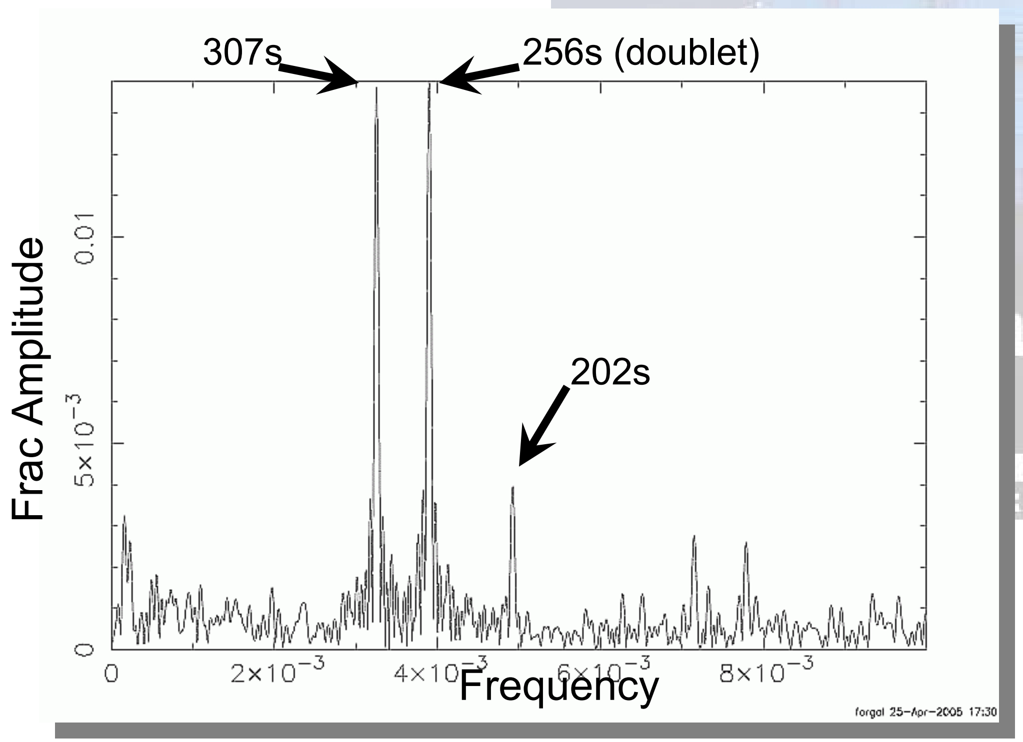




Light Curve



Fourier Transform



Asteroseismology

- Unique way to look inside a star.
- Calibrate models used for measuring age of the Galaxy (Winget 1987)
- Pulsations probe the convection zone, testing our poorly understood convection theories (Montgomery 2005)

Very stable pulsations

- Some pulsational modes are highly mono-periodic ($^{dP}/_{dt} \sim 10^{-15}$, Kepler 2005)

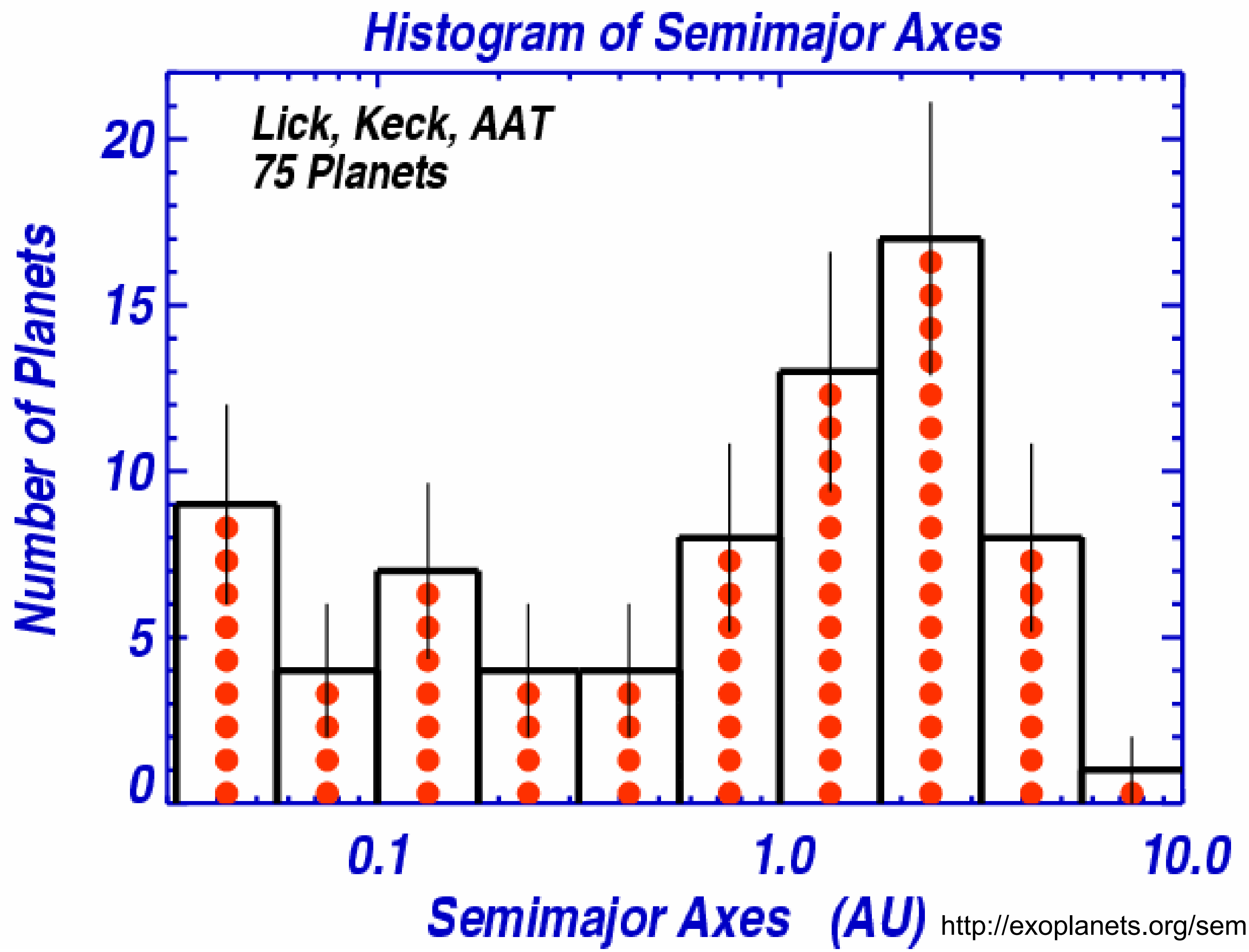
- Dominant source of period drift is cooling of star.

- Stable pulsations are the accurate clocks we use to find planets

Why look at DAVs?

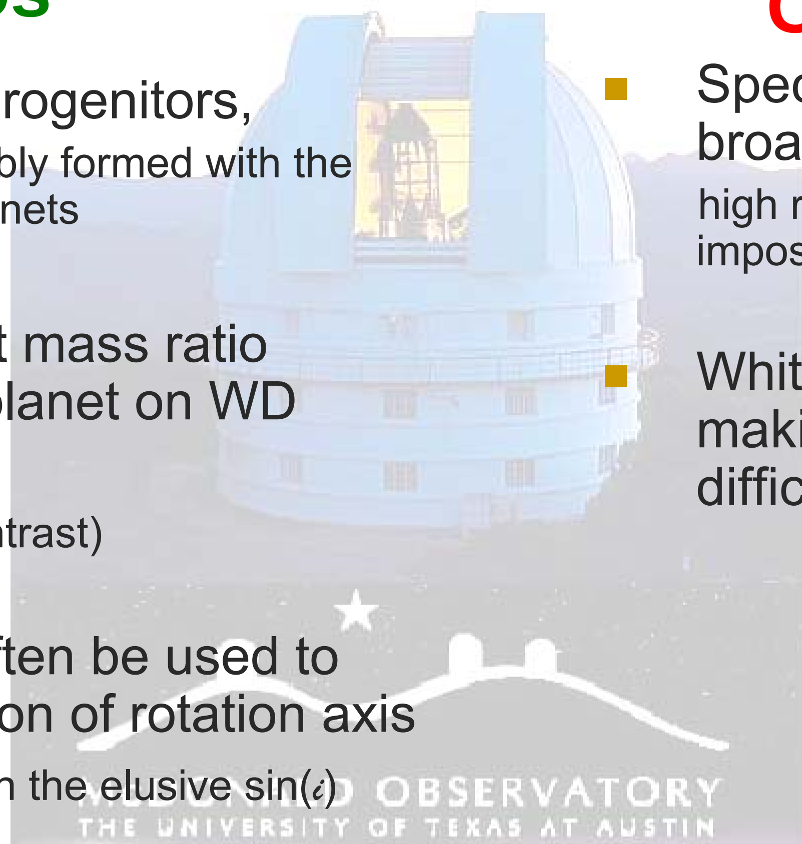
- White dwarves were once main sequence stars.
- Star:planet mass ratio lower than for MS progenitor
- Our method is more sensitive to planets at larger orbital separations
- Pulsations can often be used to measure inclination of rotation axis, providing information on $\sin(i)$

The radial velocity question



http://exoplanets.org/semimajor_axes.html

White Dwarves as Planet Hosts



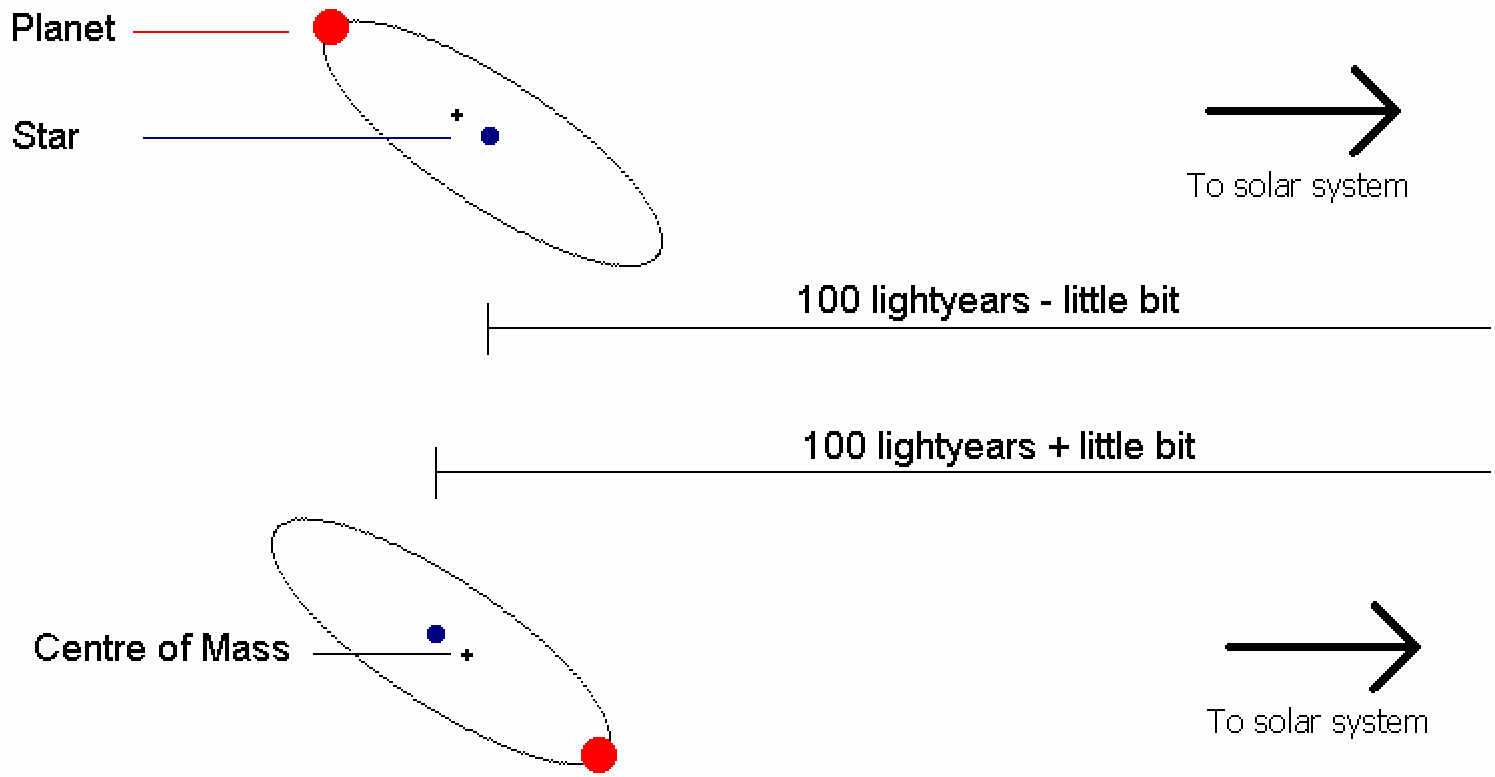
Pros

- Main sequence progenitors,
  any planets presumably formed with the star, unlike pulsar planets
- Lower star-planet mass ratio means effect of planet on WD motion greater
  (also a lower flux contrast)
- Pulsations can often be used to measure inclination of rotation axis
  yielding information on the elusive sin(¿)

Cons

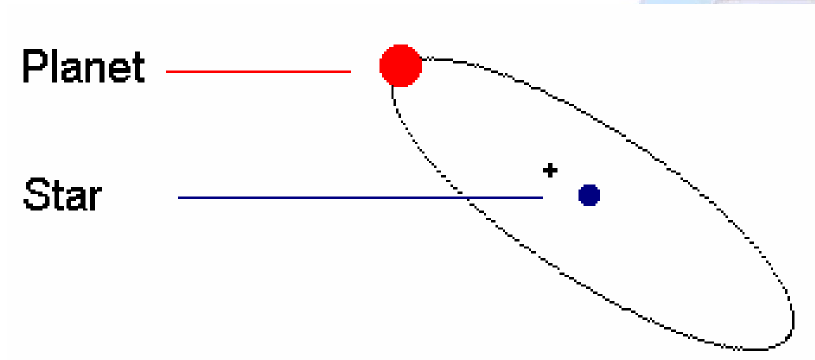
- Spectrum dominated by broad Balmer lines
  high resolution radial velocity impossible.
- White Dwarves are faint, making observations more difficult.

Using Pulsations to Probe Planets



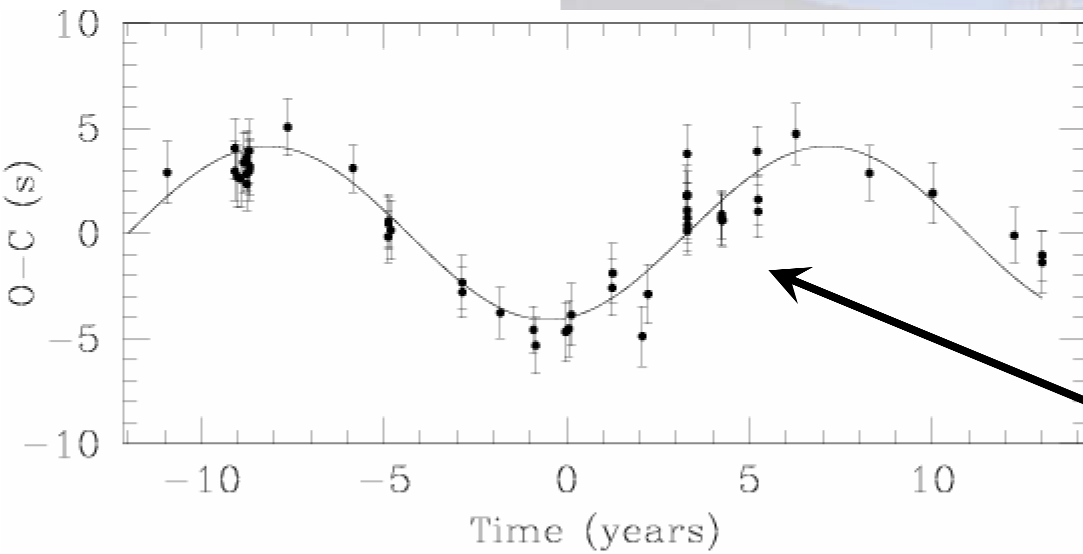
$$\text{Time of Travel} = \frac{\text{Distance}}{\text{Speed of light}}$$

Sensitivity

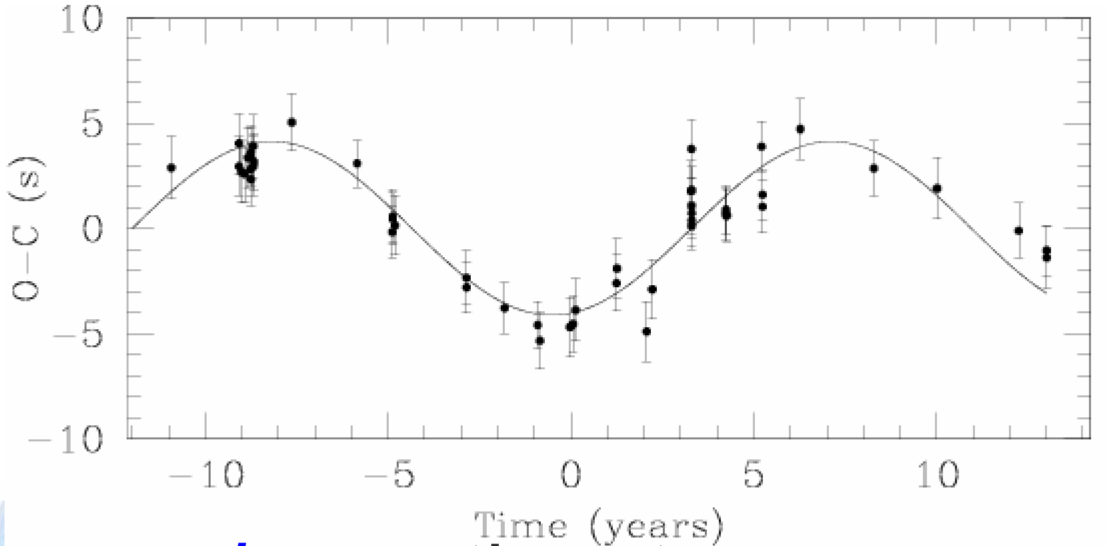


- Change in arrival time greater for planets with:
  - Large Mass
  - Large orbital Separation
  - Orbits along our line of sight.

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



Simulated effect of Jupiter on pulse arrival times



- Planets in long orbits will slowly *accelerate* the star resulting in a changing observed period:

Pulsation Period — Mass of Planet

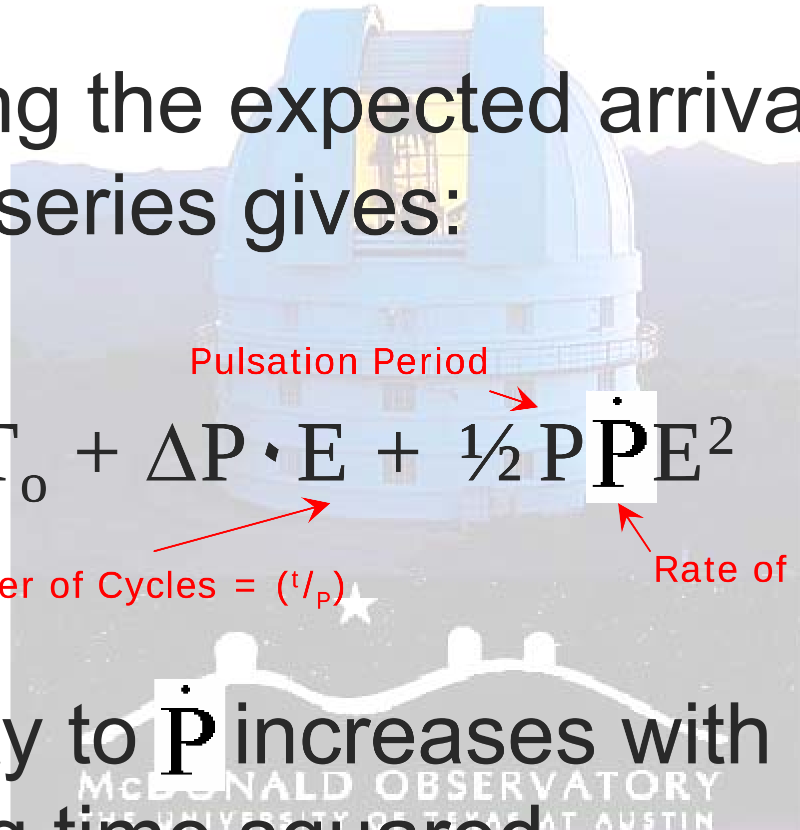
$$\dot{P}_{plan} = \frac{P}{c}\frac{G\,m_p}{a^2}\sin i$$

Orbital Separation

(Kepler 1991)

- Cooling of star, proper and orbital motion also create $\dot{P}$

Measuring $\dot{P}$



- Expanding the expected arrival time as a Taylor series gives:

- $$O\text{-}C = \Delta T_o + \Delta P \cdot E + \tfrac{1}{2} P \dot{P} E^2$$

  Pulsation Period

  Number of Cycles = $(^t/_P)$

  Rate of change of Period

- Sensitivity to $\dot{P}$ increases with observing time squared

Will Planets survive Red Giant Phase? - Theory

- When our sun dies, Mercury engulfed by red giant, Mars survives (Sackmann 1993)

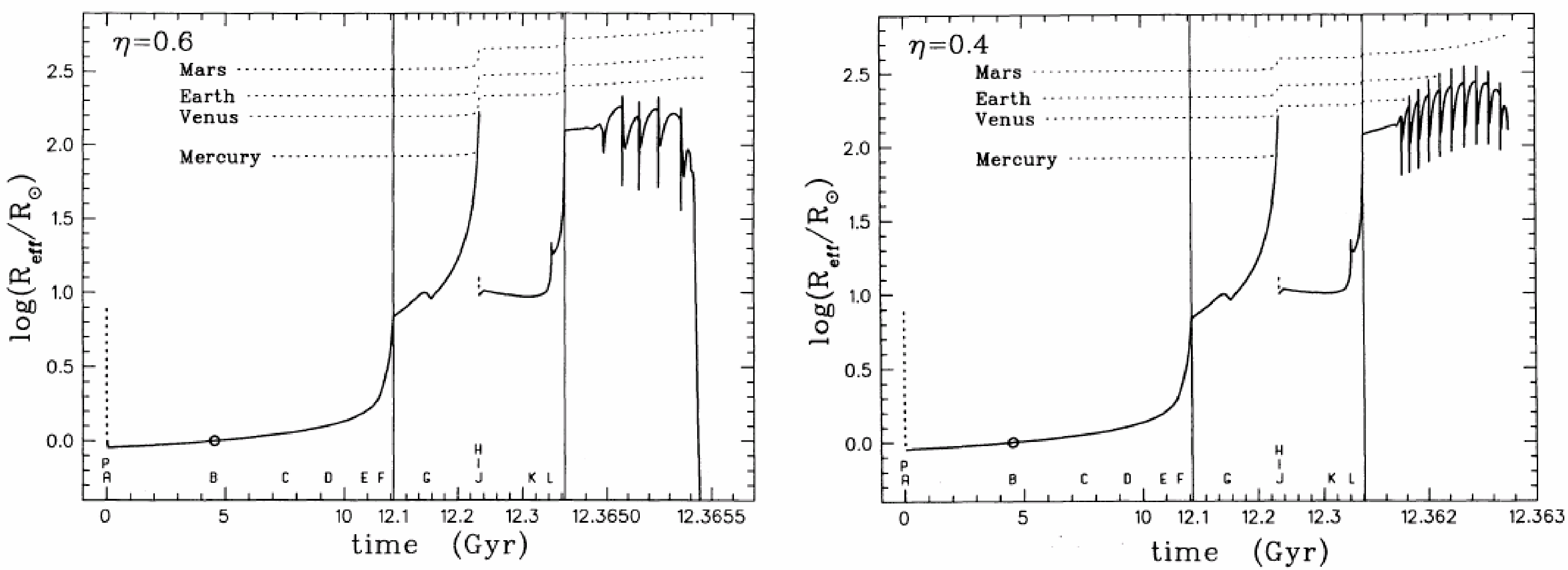


FIG. 7a FIG. 7b

FIG. 7.—Changes in the solar radius as a function of time. (*a*) Our preferred mass-loss case, with $\eta = 0.6$; (*b*) our low mass-loss case, with $\eta = 0.4$. The radial oscillations on the right are due to helium shell flashes. The mean orbital radii of the inner planets are also shown as a function of time (*dotted lines*); note changes in these orbital radii, due to changes in the mass of the Sun. Symbols have the same meaning as in Fig. 2.

Will Planets survive Red Giant Phase? - Theory

- If $\tau_{\text{stellar mass loss}}$ >> orbital period, single planets will drift outward with mass loss (Burleigh 2002).

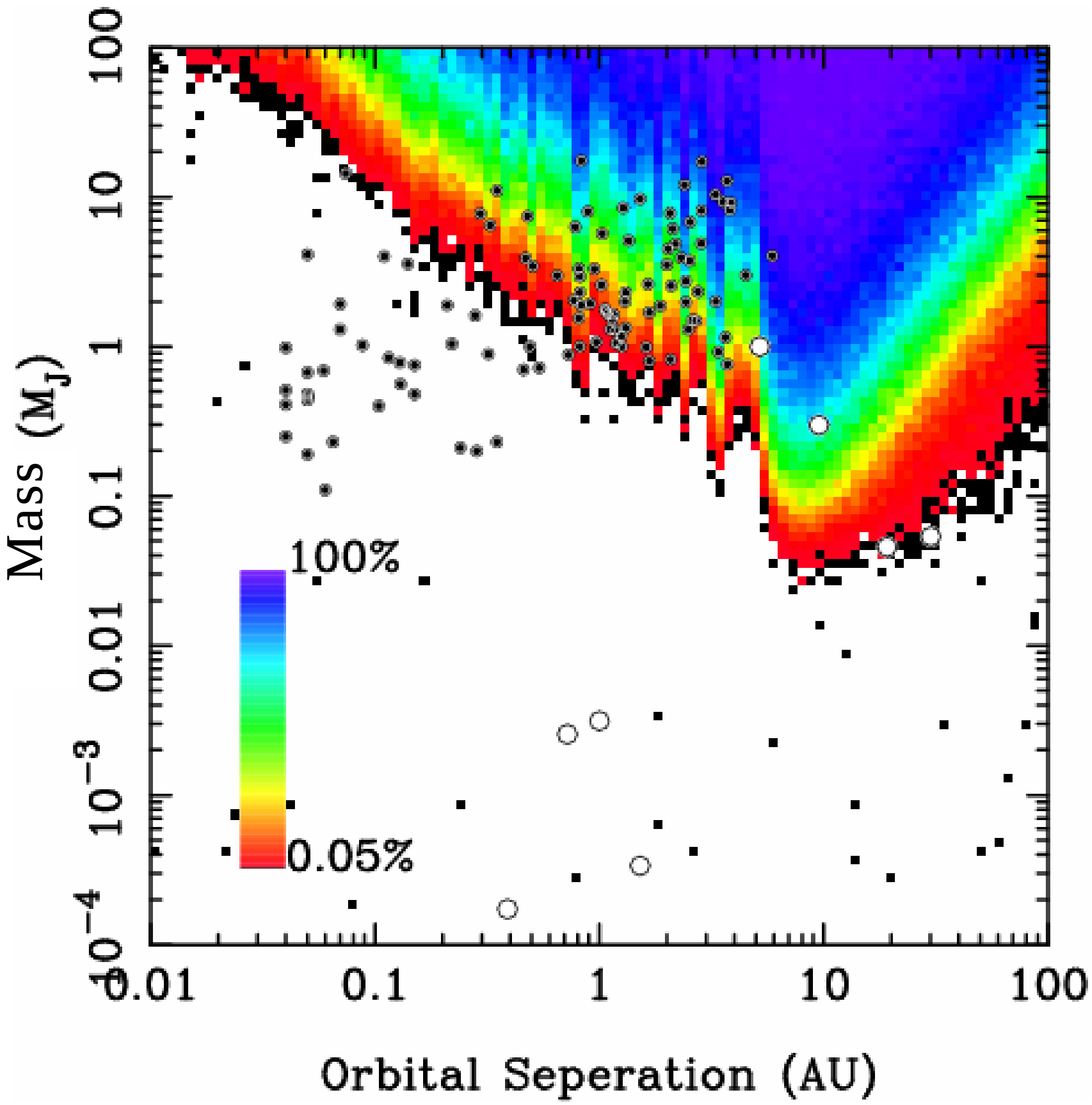
$$a_f = (M_i/M_f)a_i$$

- Duncan & Lissauer (1998) predict orbital stability for greater than 10^9 years after Red Giant.

Will Planets survive Red Giant Phase? - Empirical Evidence

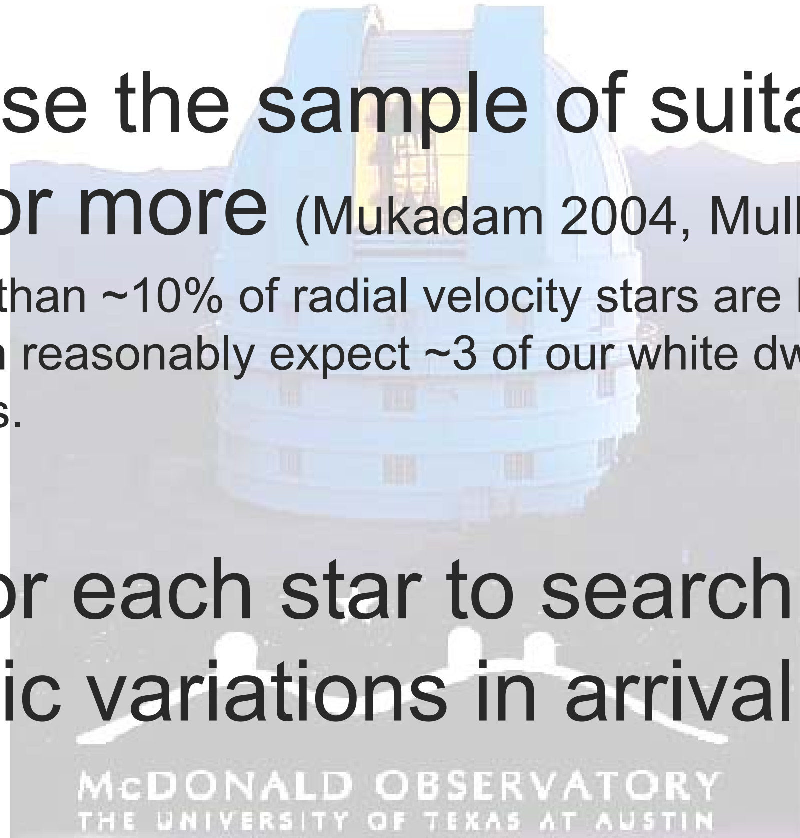
- Discovery of 4 planets around K Giant stars by RV method (e.g Frink et al. 2002)
- White Dwarf, Main Sequence & $4M_J$ exoplanet system Gl 86B
  (although planet is only 0.11 AU from MS star)

Planet detection probability for G117 based on 30 years of archival data

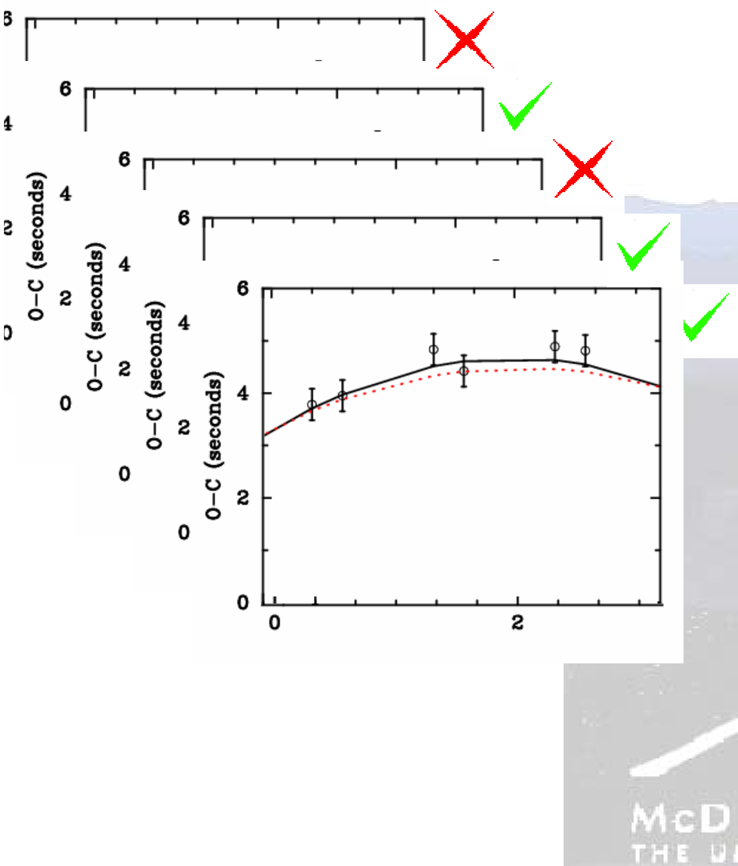


The Plan

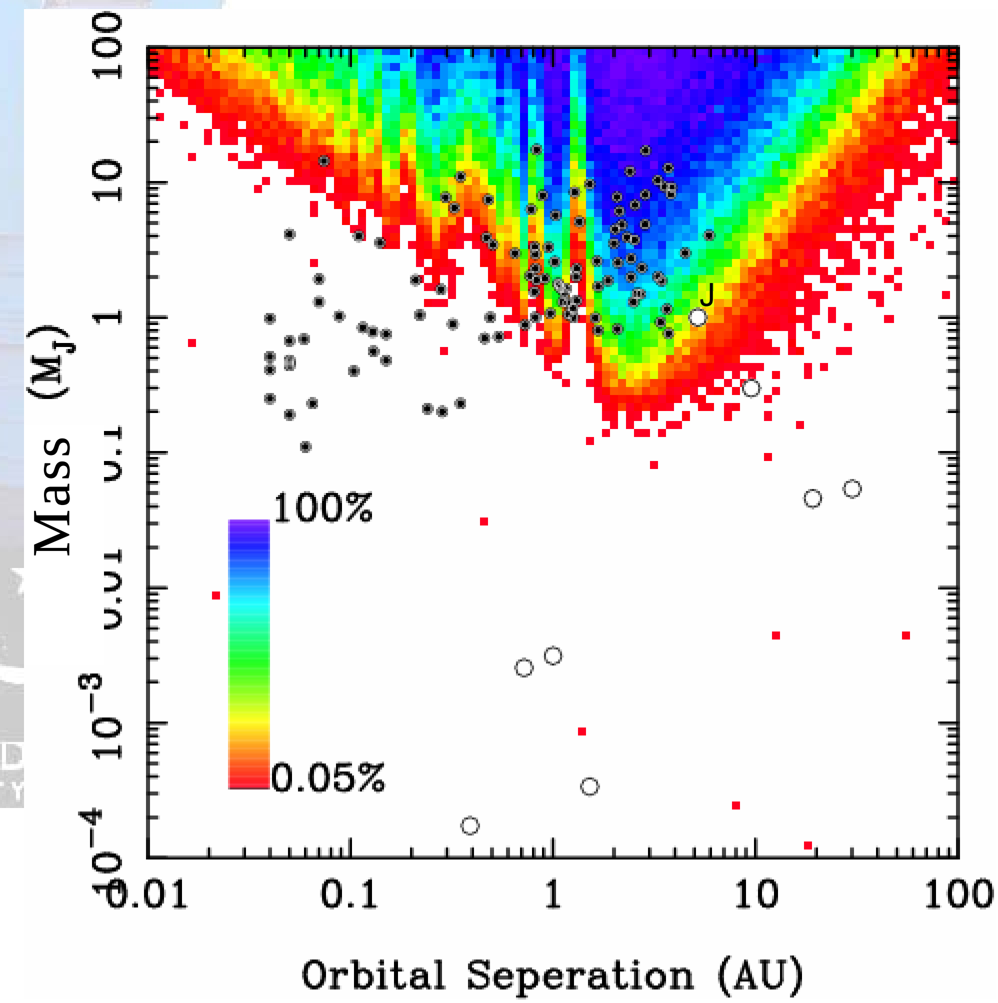
- Increase the sample of suitable stars to 30 or more (Mukadam 2004, Mullally 2005)
  - Given than ~10% of radial velocity stars are known to have stars, we can reasonably expect ~3 of our white dwarves to habour planets.
- Monitor each star to search for periodic variations in arrival time
- Incidental science along the way



The Expected Result

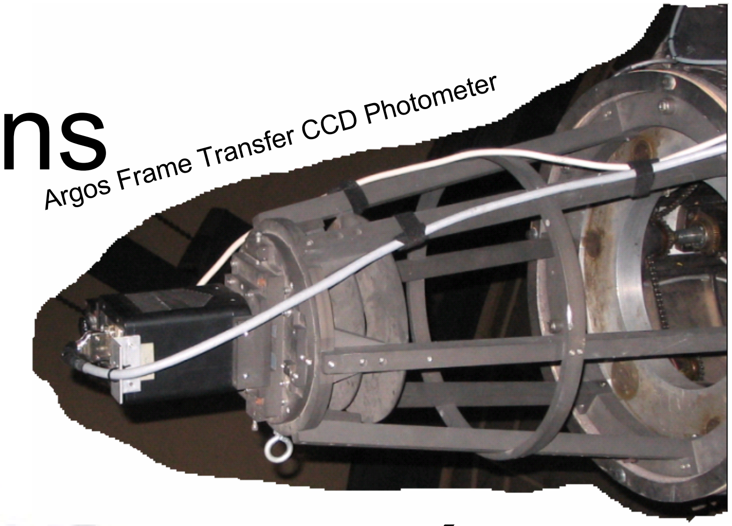


Probablity of detection

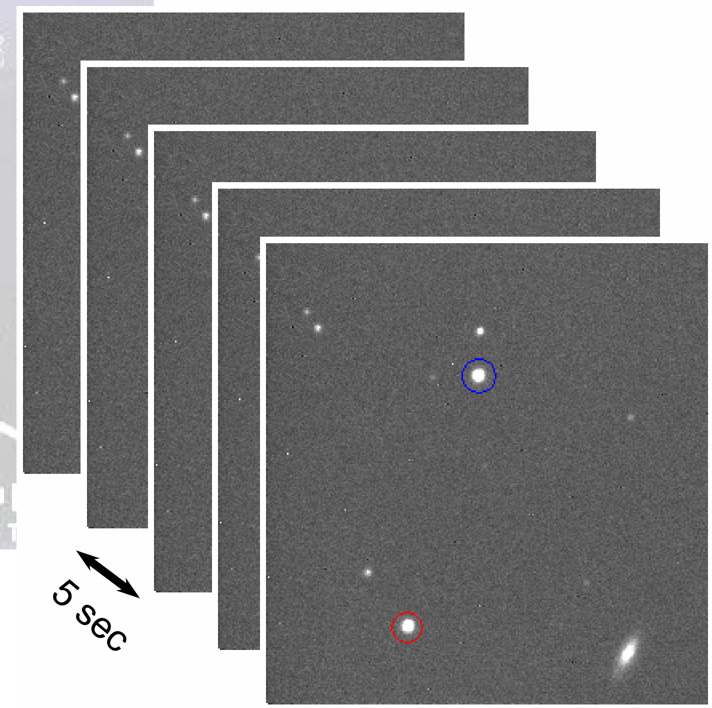


The Observations

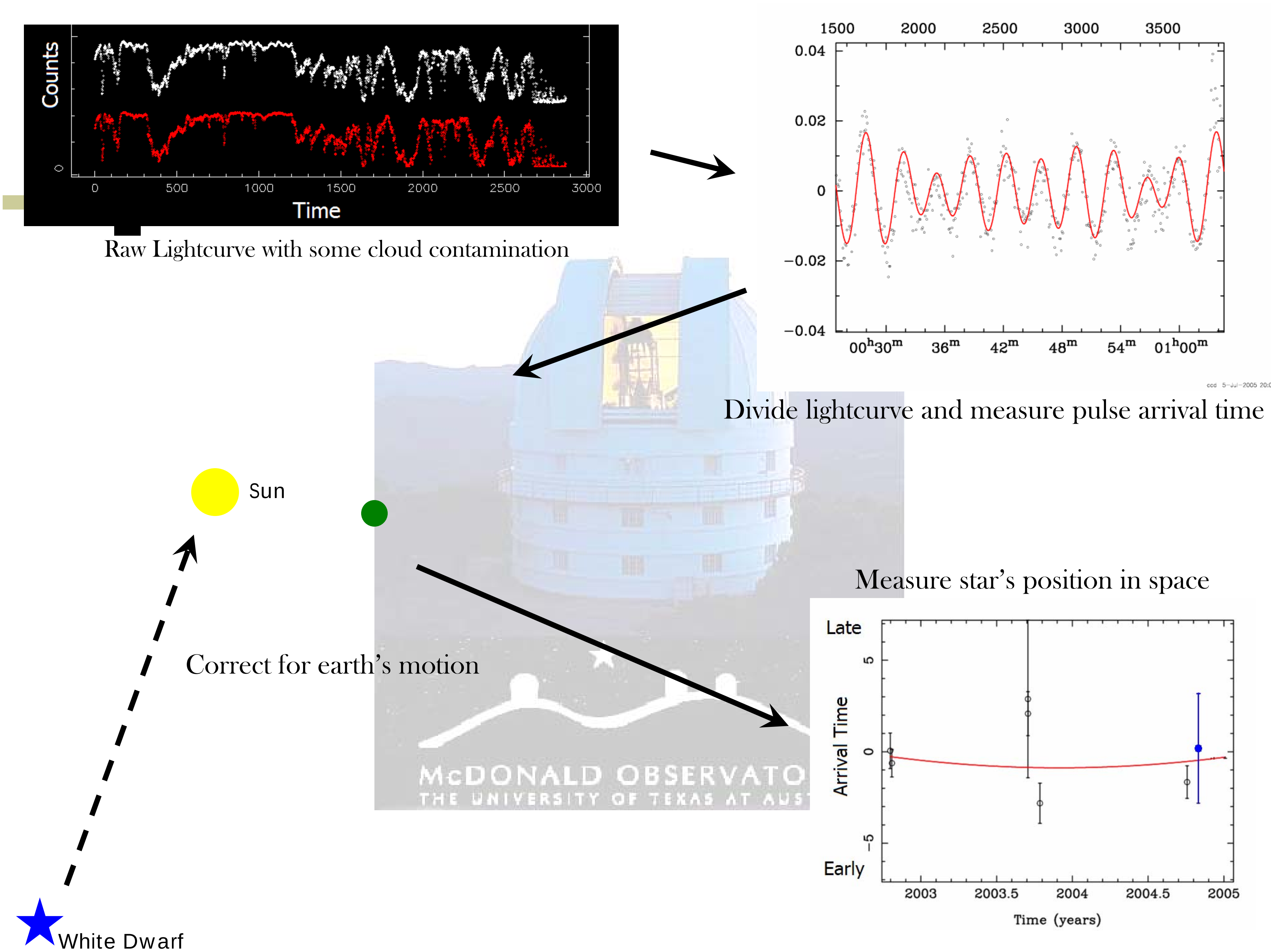
2.1m Otto Struve Telescope
at McDonald Observatory



Some Data Reduction...



Repeated short integrations


Counts
Time
0
500
1000
1500
2000
2500
3000
Raw Lightcurve with some cloud contamination
1500
2000
2500
3000
3500
0.04
0.02
0
−0.02
−0.04
00h30m
36m
42m
48m
54m
01h00m
Divide lightcurve and measure pulse arrival time
Sun
Correct for earth's motion
McDONALD OBSERVATO
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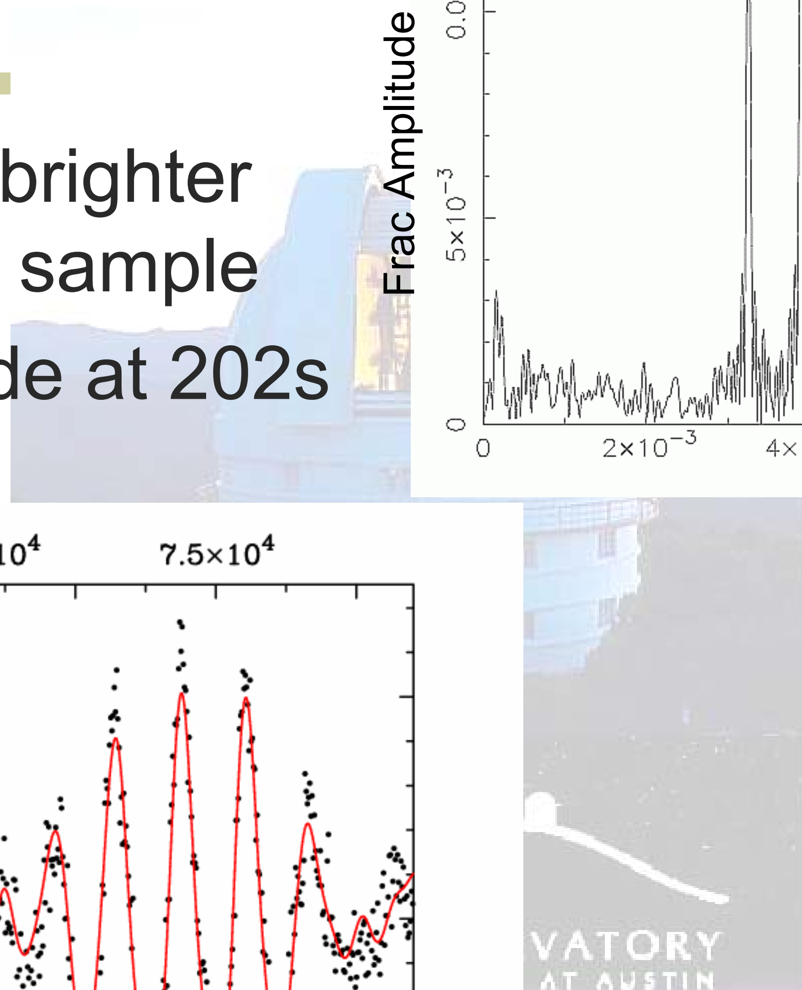
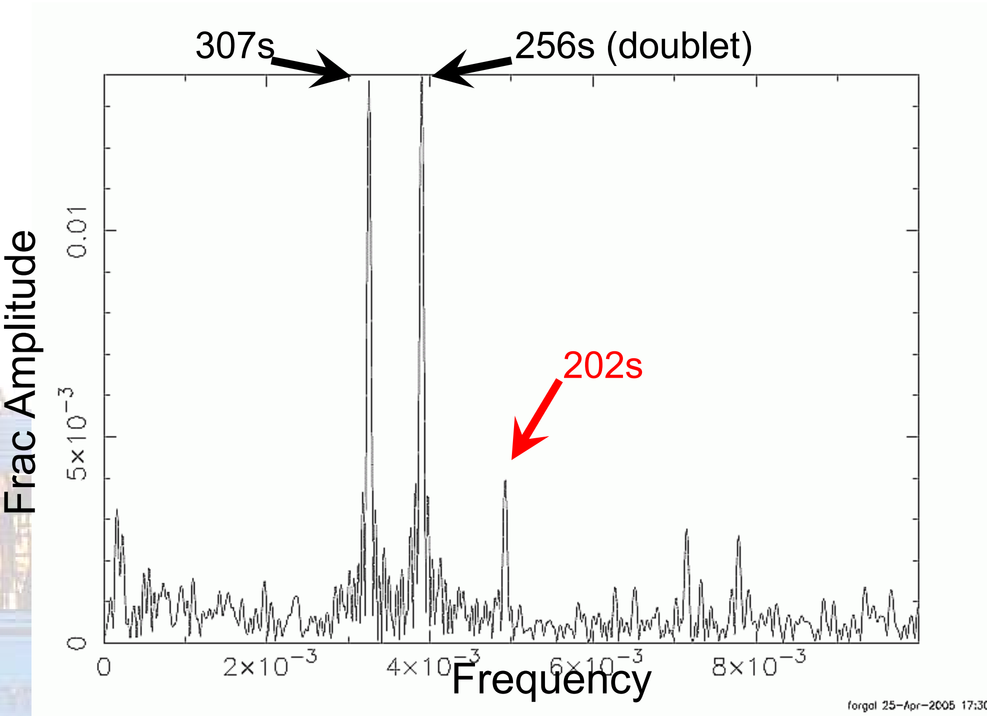
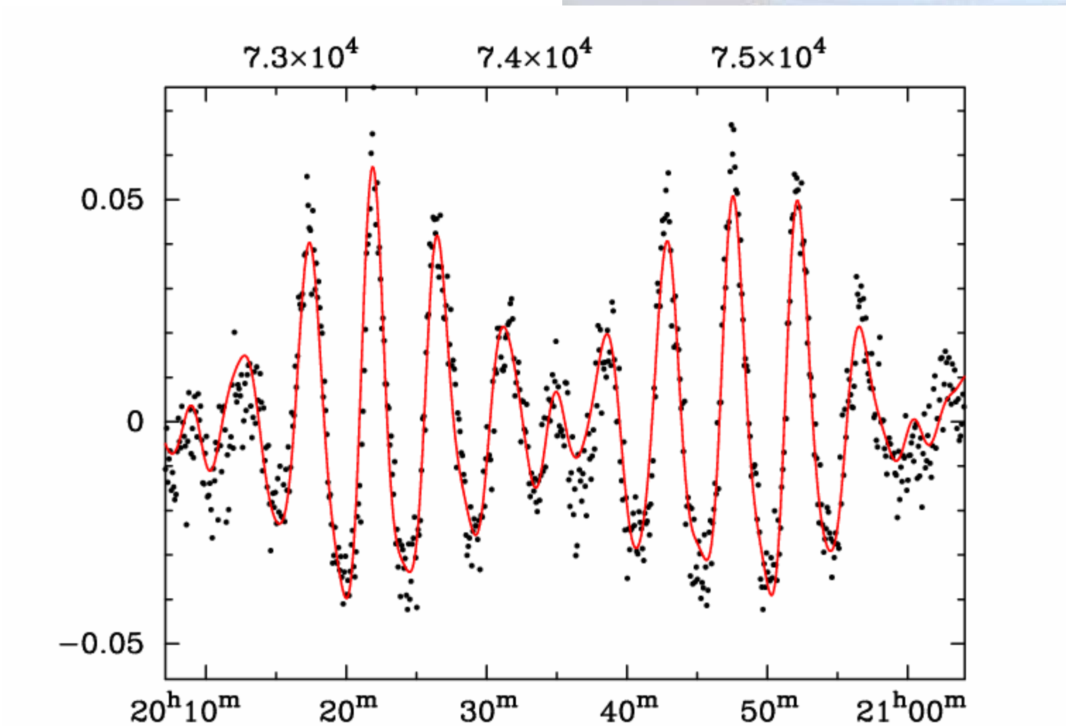
Measure star's position in space
Late
Early
Arrival Time
5
0
−5
2003
2003.5
2004
2004.5
2005
Time (years)
White Dwarf

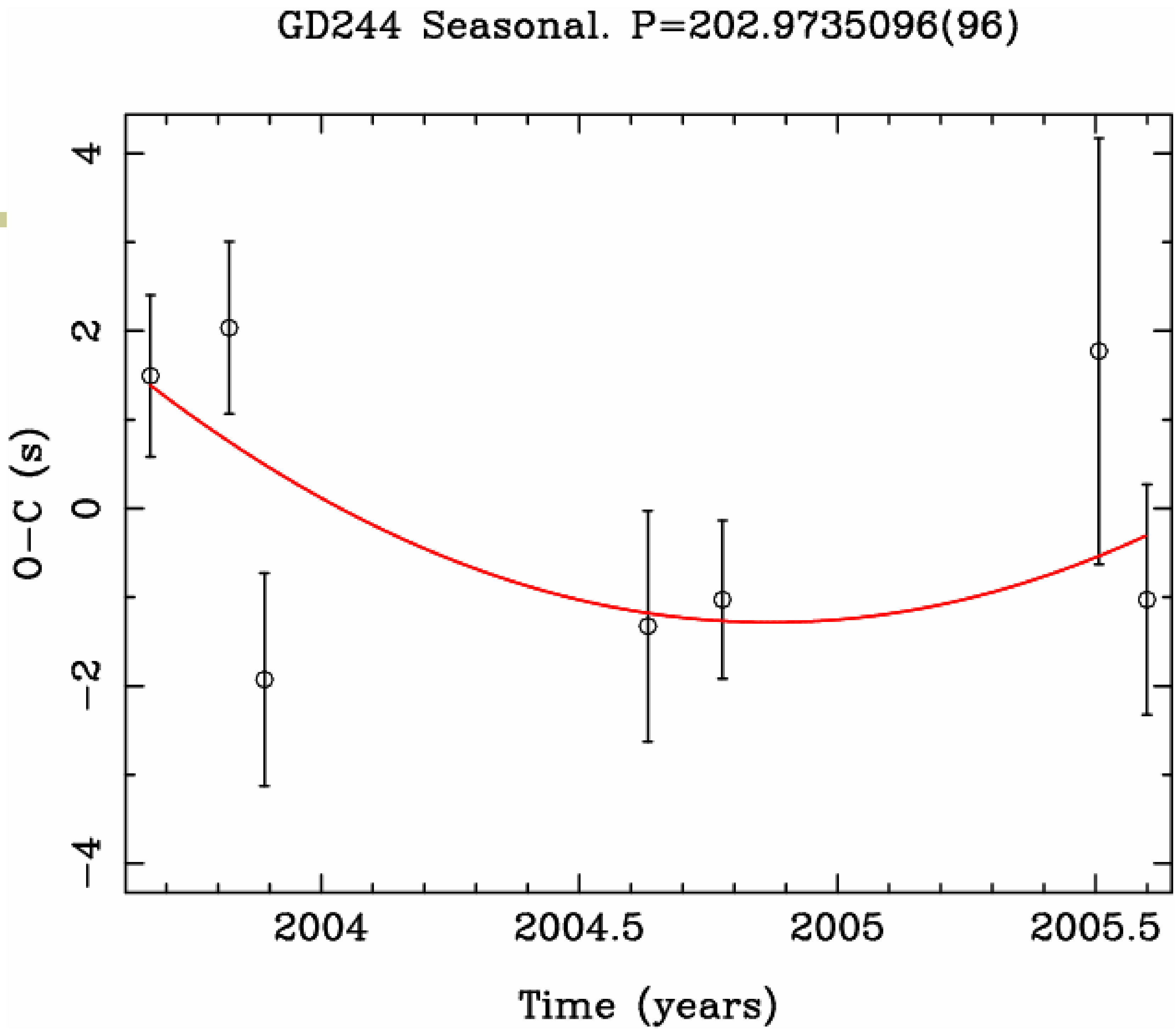
GD244

- One of the brighter stars in our sample
- Singlet mode at 202s



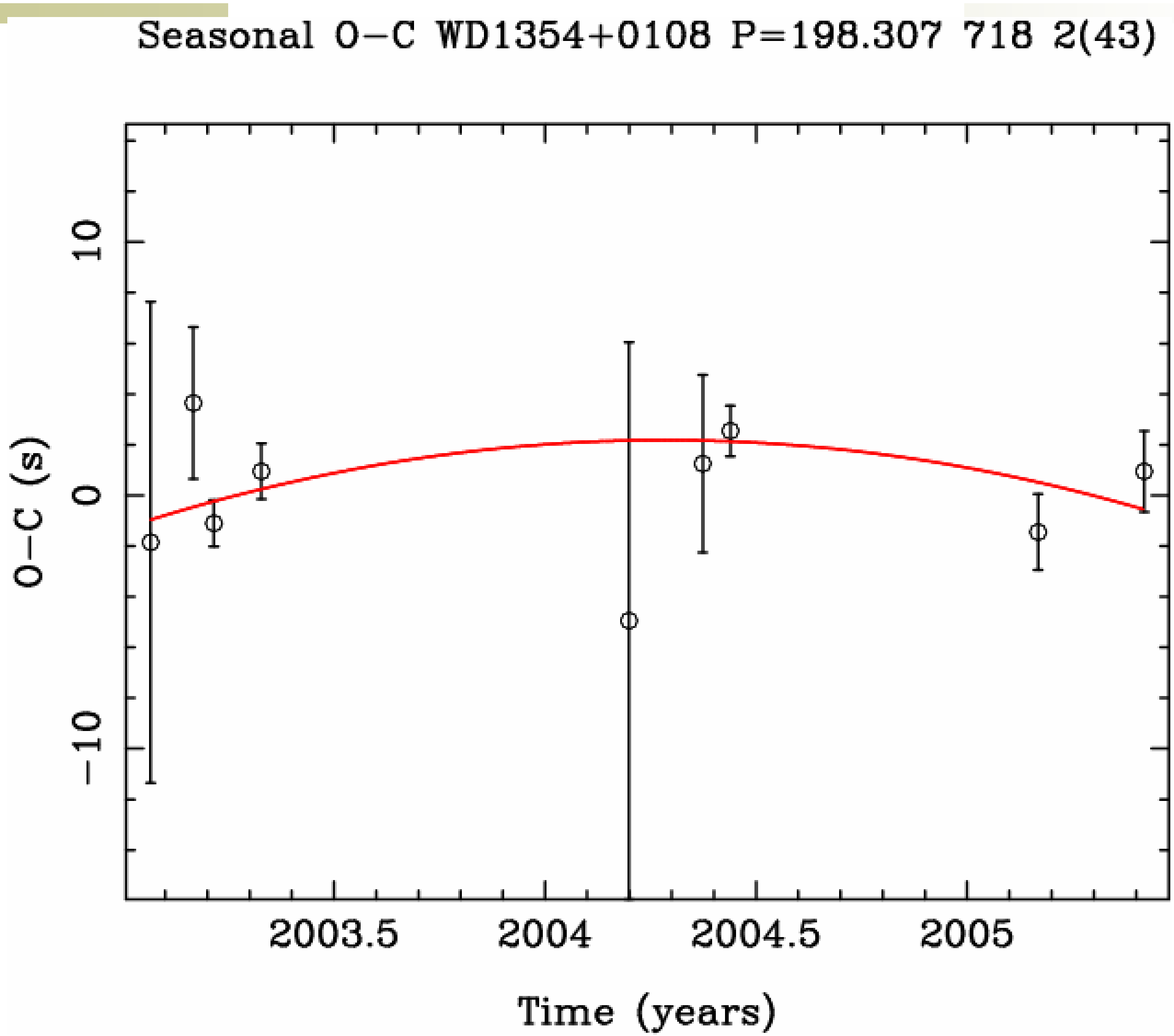




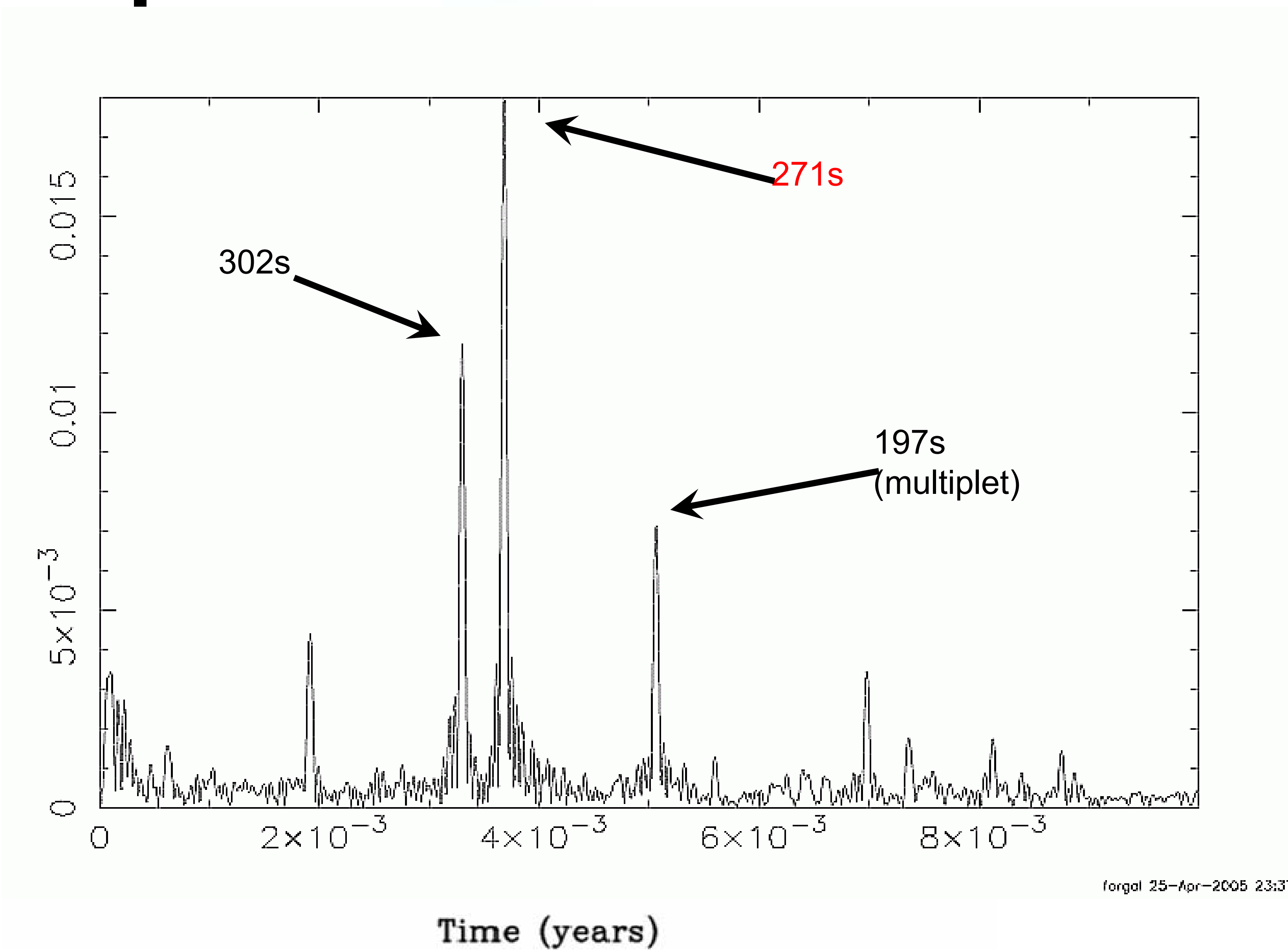


GD244 Seasonal. P=202.9735096(96)
O−C (s)
4
2
0
−2
−4
2004
2004.5
2005
2005.5
Time (years)

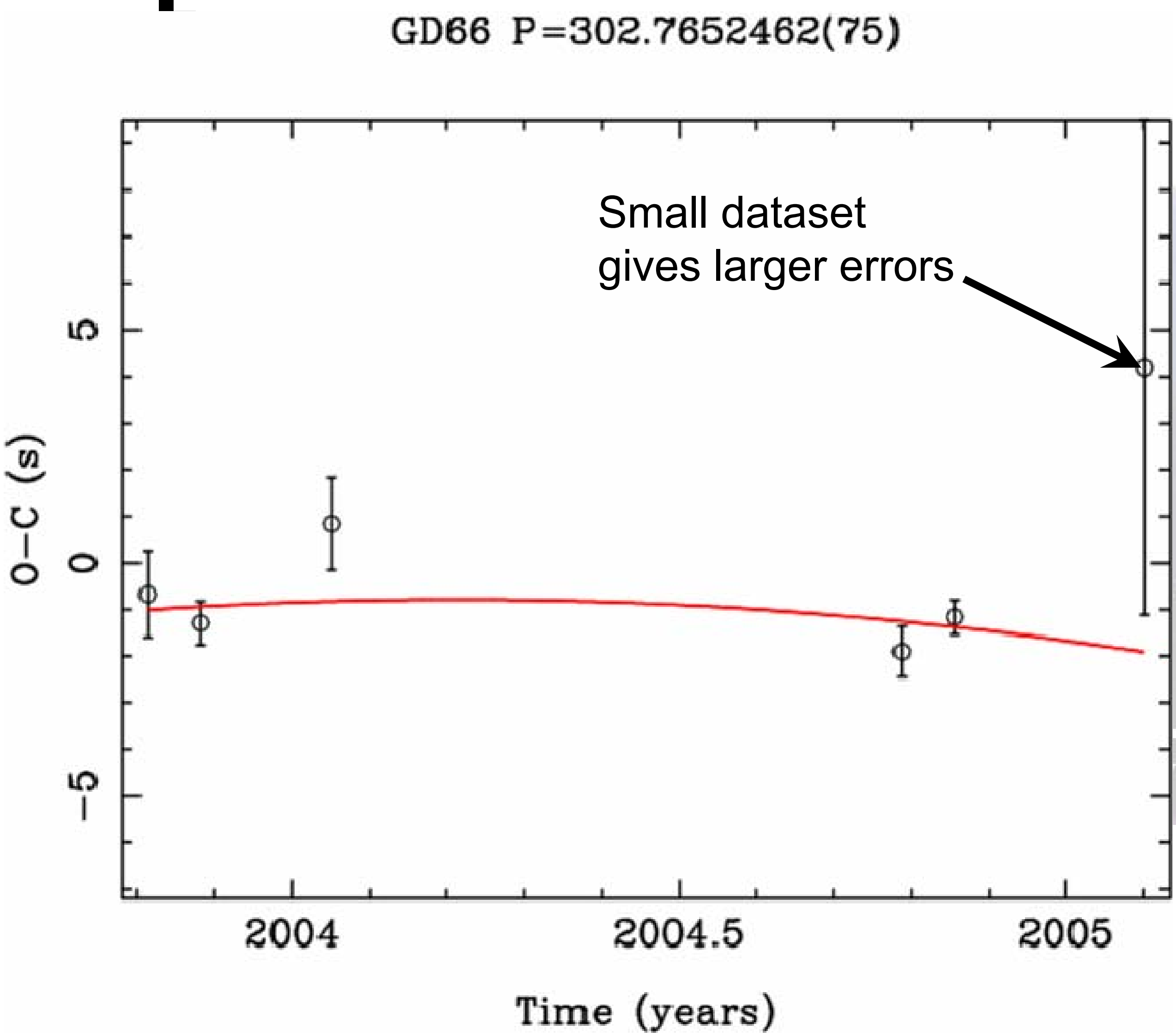
WD1354+0108


Seasonal O−C WD1354+0108 P=198.307 718 2(43)
O−C (s)
10
0
−10
2003.5
2004
2004.5
2005
Time (years)

GD66

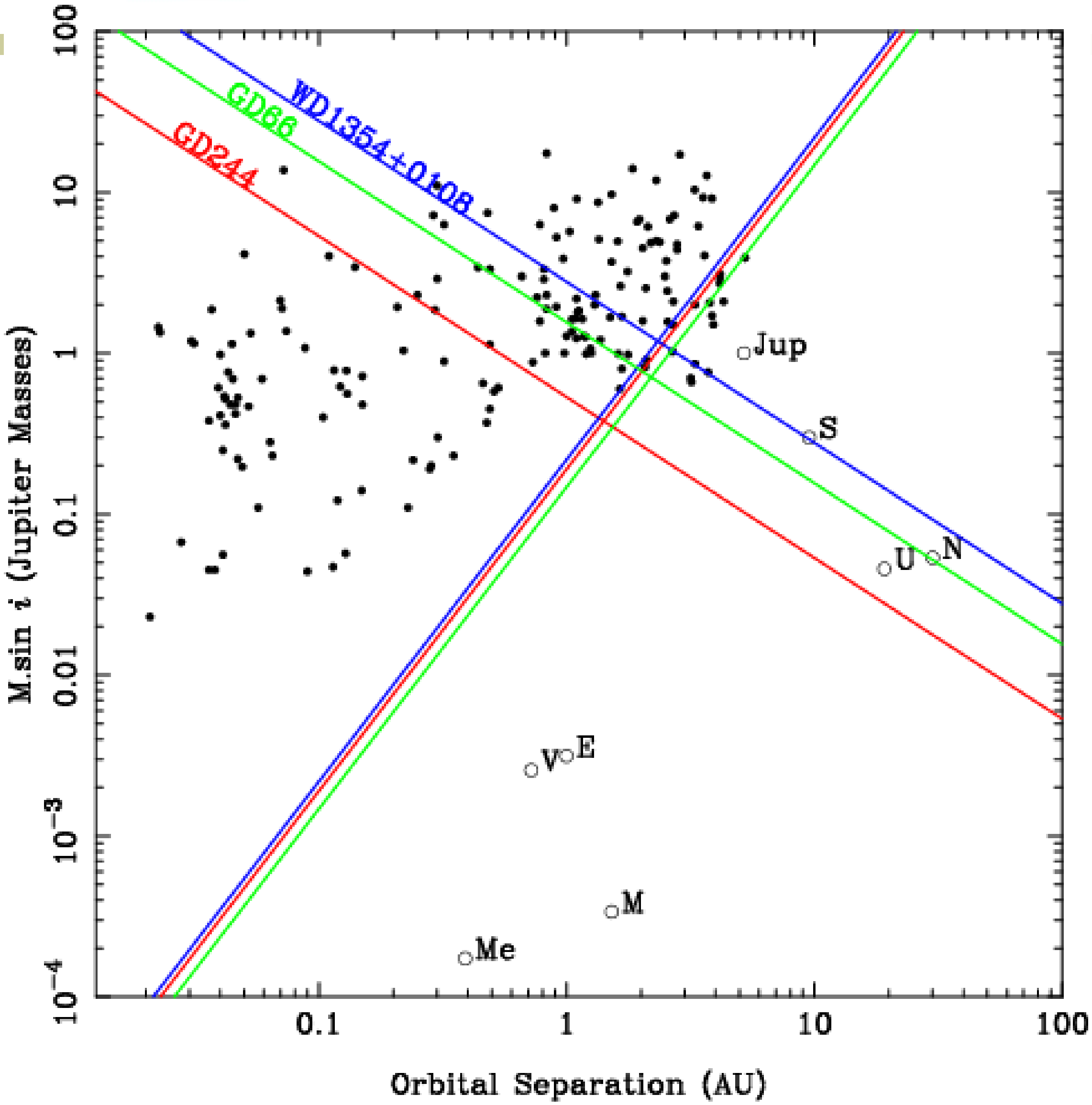


y greater
errors



- A planet (or other body) would affect both modes equally
- This must be something internal to the star
    - An intermittent mode close to 271s may cause phase jitter.

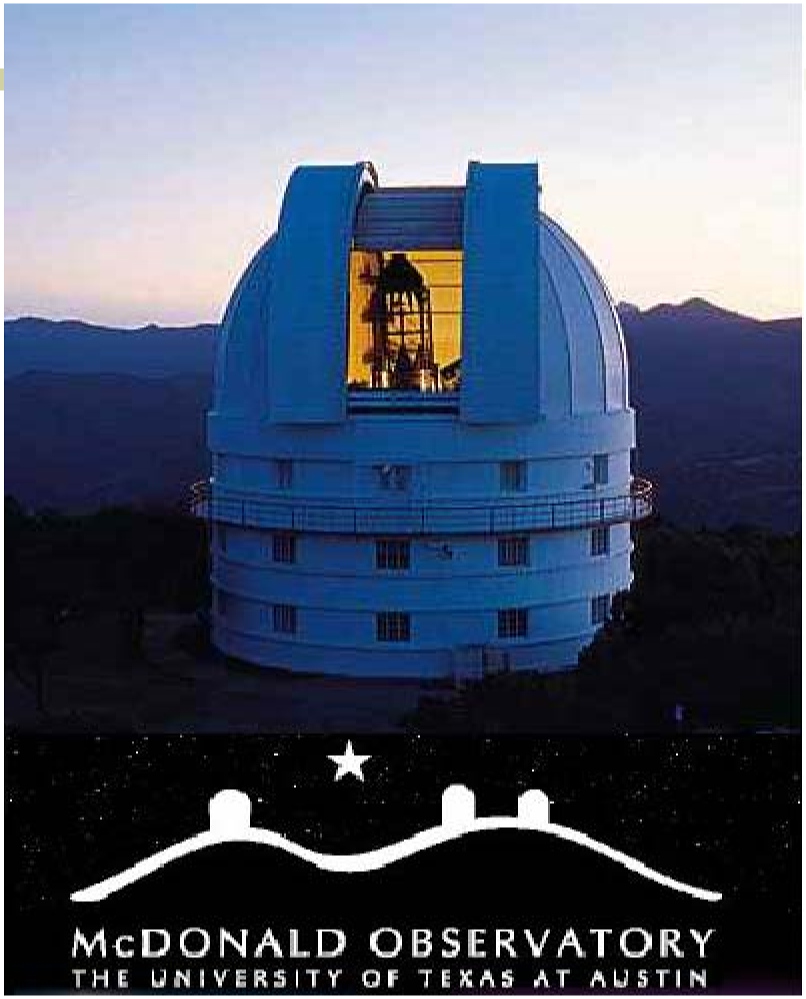
The Results



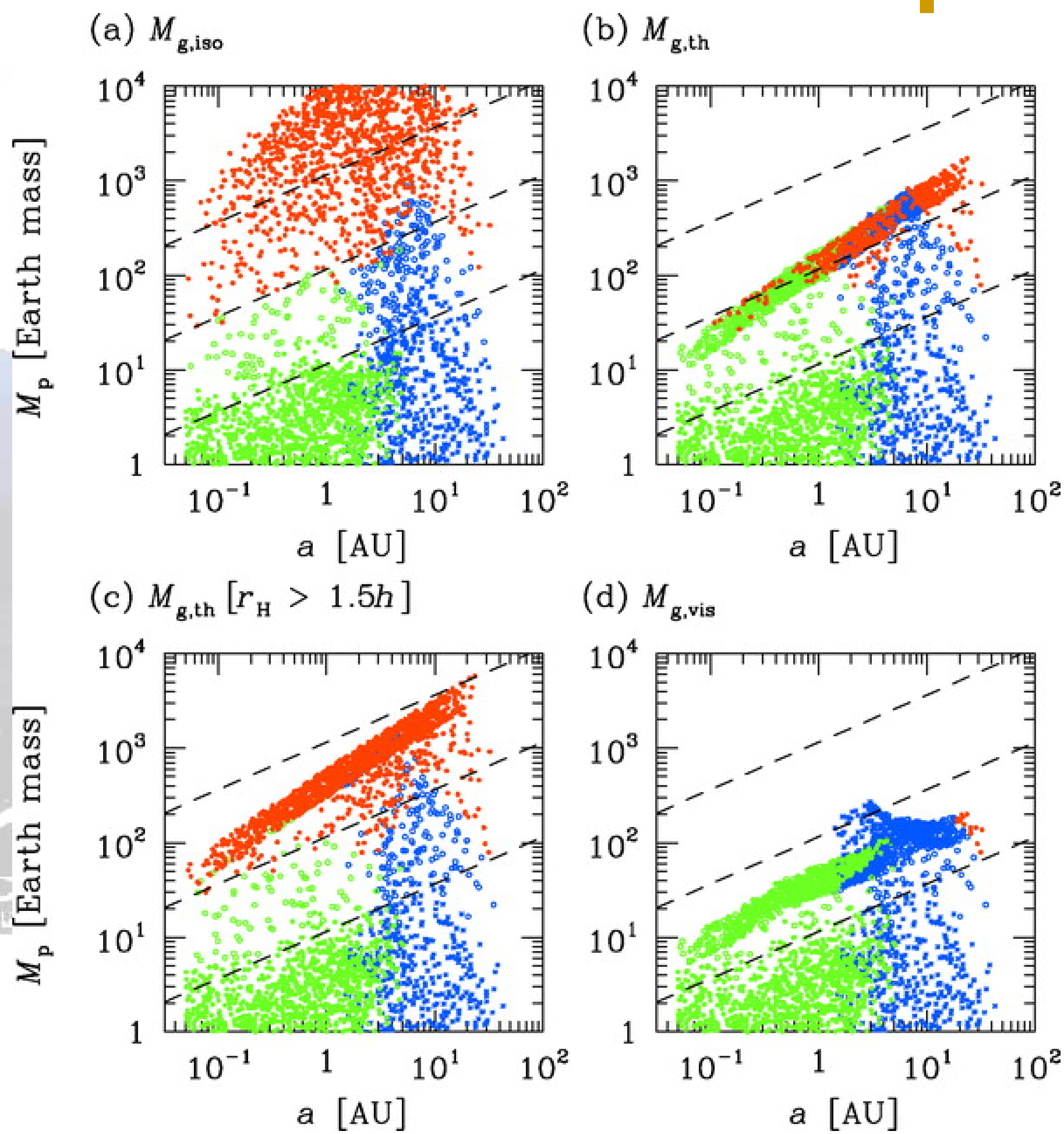
WD1354+0108
GD66
GD244
Jup
S
U
N
V
E
M
Me
M.sin i (Jupiter Masses)
Orbital Separation (AU)
100
10
1
0.1
0.01
10^{-3}
10^{-4}
0.1
1
10
100

Conclusions

- White Dwarves are ideal laboratories for everything from planets to the age of the Galaxy
- An orbiting planet can measurably affect the observed arrival time of these pulses here on earth.
- Planets further out are easier to detect using this method


McDONALD OBSERVATORY
THE UNIVERSITY OF TEXAS AT AUSTIN

Testing Core Accretion and Disk Instability:

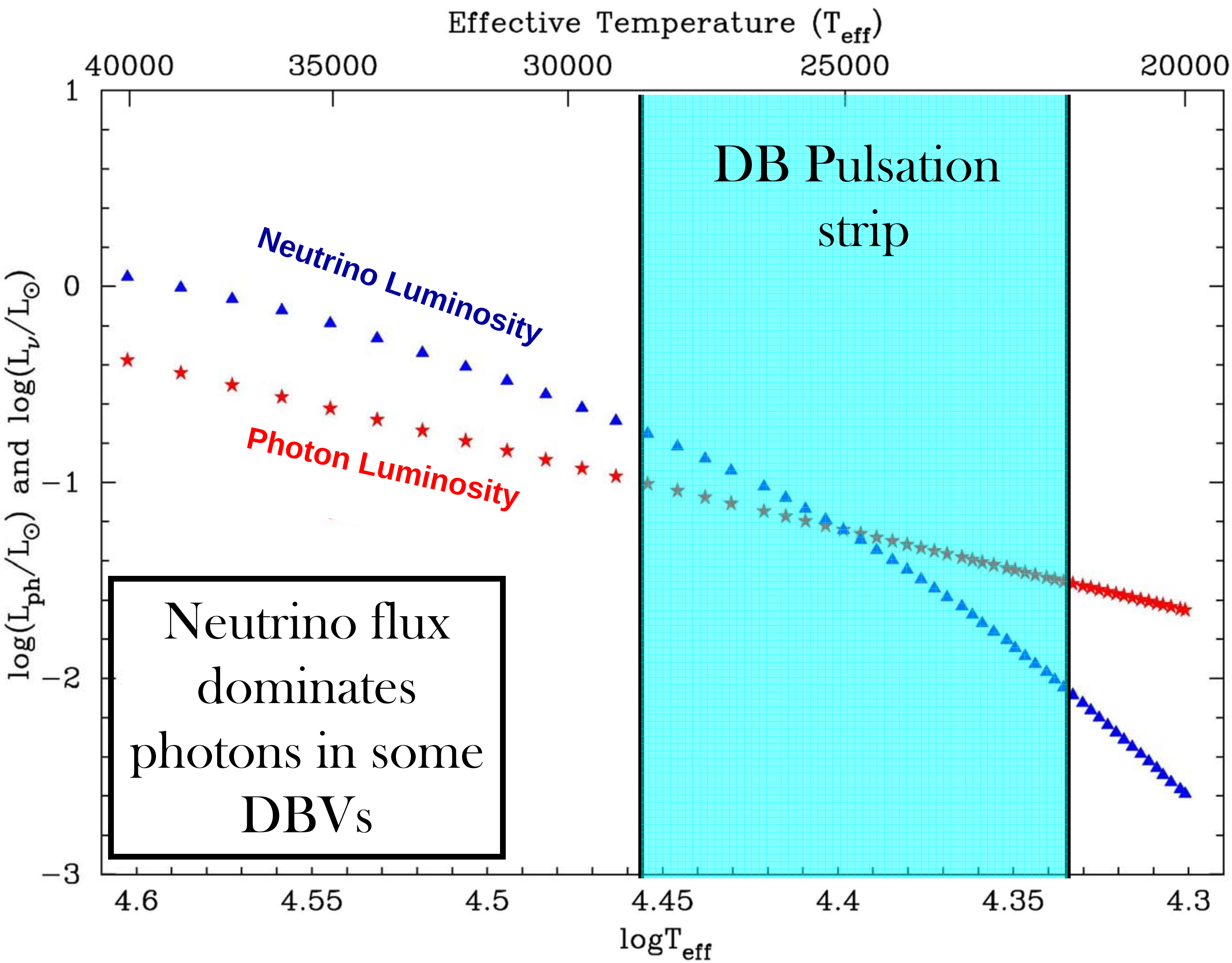


Plasmon Neutrinos

- Neutrinos not produced exclusively in nuclear reactions
- In a hot dense plasma, photons can transform themselves into neutrinos
- $\gamma \longrightarrow e^- + e^+ \longrightarrow \nu_e + \bar{\nu}_e$

Needs high energy photons

and strong electric field of nearby nucleus



Effective Temperature (T_{eff})
40000
35000
30000
25000
20000
1
0
−1
−2
−3
$\log(L_{ph}/L_\odot)$ and $\log(L_\nu/L_\odot)$
DB Pulsation strip
Neutrino Luminosity
Photon Luminosity
Neutrino flux dominates photons in some DBVs
4.6
4.55
4.5
4.45
4.4
4.35
4.3
$\log T_{eff}$

Winget (2004)

- Talk about number of planets expect to find
- Emph that we expect the planets to form far out (3-10 AU)