STELLAR ARCHEOLOGY:

What White Dwarf Stars Tell Us About the History of the Galaxy

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"Stars, Companions and Their Interactions:
A Memorial to Robert H. Koch"
Villanova University, Villanova PA, August 10, 2011

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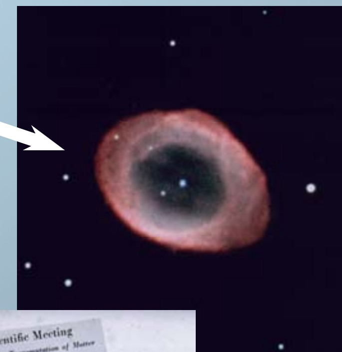
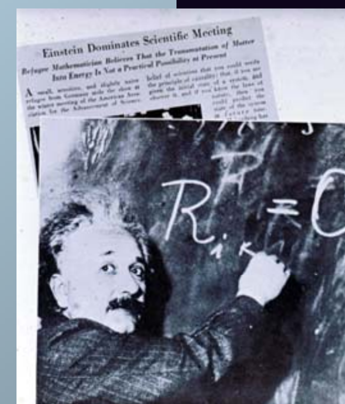
AST-0807919

White Dwarf Stars



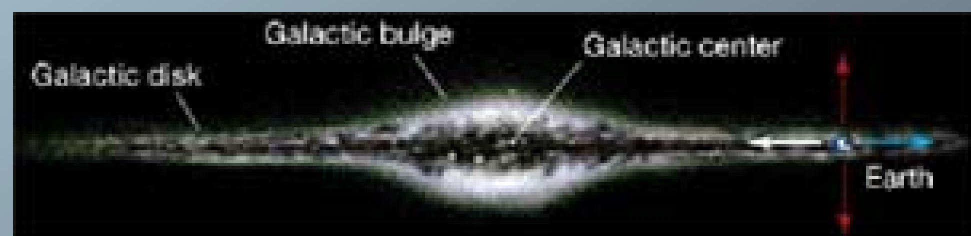
End product of stellar evolution

star formation history
mass recycling



Test of general relativity

mass-radius relation
gravitational redshifts, masses

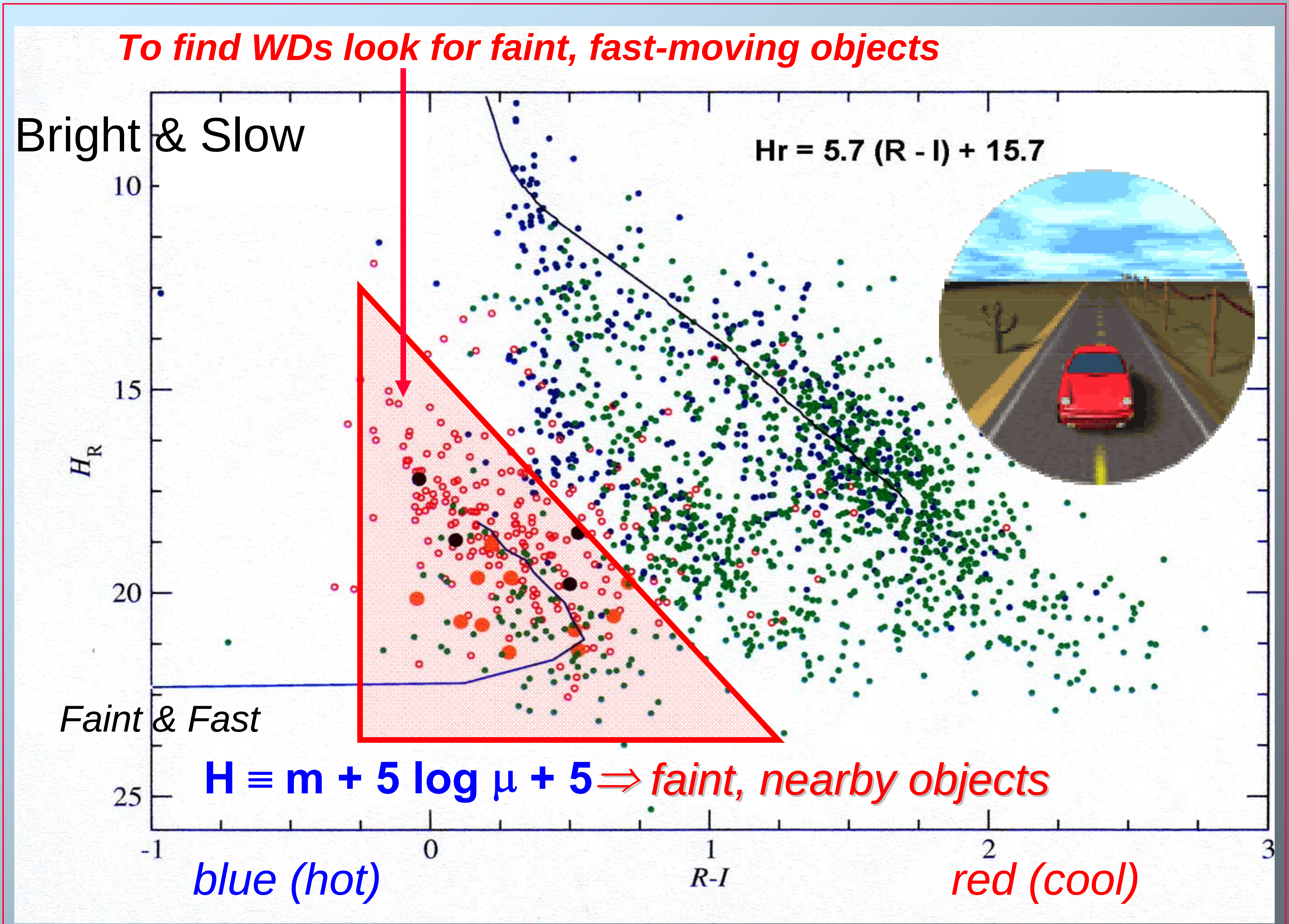


Galactic structure

thick/thin disk, halo
dark matter content

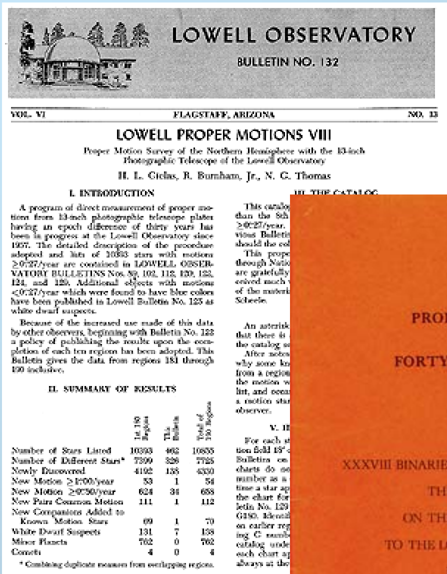
Cosmology

age of Galaxy & Universe
supernovae & dark energy


To find WDs look for faint, fast-moving objects
Bright & Slow
Hr = 5.7 (R - I) + 15.7
10
15
20
25
H_R
Faint & Fast
H ≡ m + 5 log μ + 5 ⇒ faint, nearby objects
-1
0
1
2
3
R-I
blue (hot)
red (cool)

"Fragile" Binaries: Definition

"…small galactic clusters containing stars of the same age and composition." –Greenstein 1986



LOWELL OBSERVATORY

BULLETIN NO. 132

VOL. VI FLAGSTAFF, ARIZONA NO. 13

LOWELL PROPER MOTIONS VIII

Proper Motion Survey of the Northern Hemisphere with the 13-inch Photographic Telescope of the Lowell Observatory

H. L. Giclas, R. Burnham, Jr., N. G. Thomas

I. INTRODUCTION

A program of direct measurement of proper motions from 13-inch photographic telescope plates having an epoch difference of thirty years has been in progress at the Lowell Observatory since 1957. The detailed description of the procedure adopted and lists of 10393 stars with motions ≥0″.27/year are contained in LOWELL OBSERVATORY BULLETINS Nos. 89, 102, 112, 120, 122, 124, and 129. Additional objects with motions <0″.27/year which were found to have blue colors have been published in Lowell Bulletin No. 125 as white dwarf suspects.

Because of the increased use made of this data by other observers, beginning with Bulletin No. 122 a policy of publishing the results upon the completion of each ten regions has been adopted. This Bulletin gives the data from regions 181 through 190 inclusive.

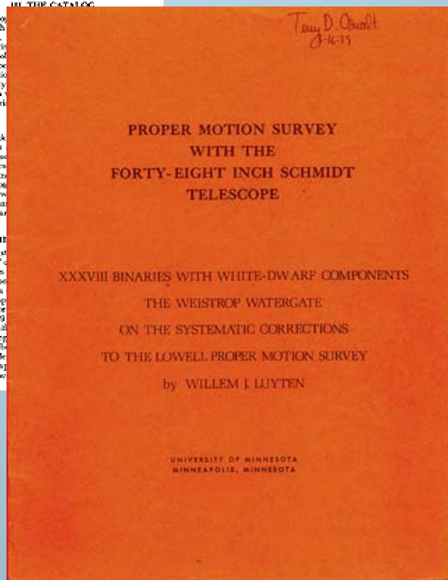
II. SUMMARY OF RESULTS

	1st 180 Regions	This Bulletin	Total of 190 Regions
Number of Stars Listed	10393	462	10855
Number of Different Stars*	7399	326	7725
Newly Discovered	4192	138	4330
New Motion ≥1″.00/year	53	1	54
New Motion ≥0″.50/year	624	34	658
New Pairs Common Motion	111	1	112
New Companions Added to Known Motion Stars	69	1	70
White Dwarf Suspects	131	7	138
Minor Planets	762	0	762
Comets	4	0	4

* Combining duplicate measures from overlapping regions.

III. THE CATALOG

Giclas et al. 1971-8



PROPER MOTION SURVEY WITH THE FORTY-EIGHT INCH SCHMIDT TELESCOPE

XXXVIII BINARIES WITH WHITE-DWARF COMPONENTS

THE WEISTROP WATERGATE

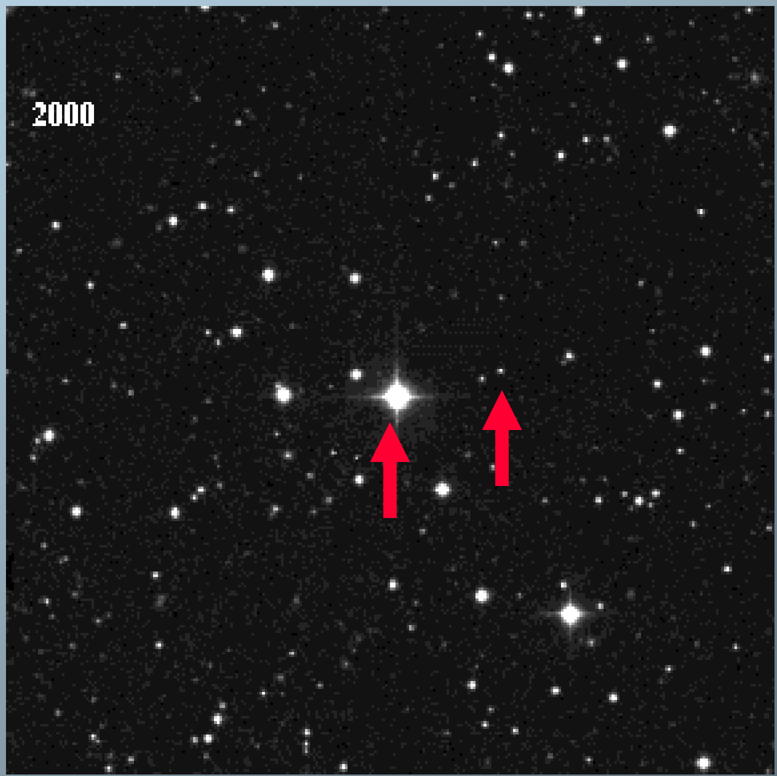
ON THE SYSTEMATIC CORRECTIONS

TO THE LOWELL PROPER MOTION SURVEY

by WILLEM J. LUYTEN

UNIVERSITY OF MINNESOTA
MINNEAPOLIS, MINNESOTA

Luyten 1969 et seq.

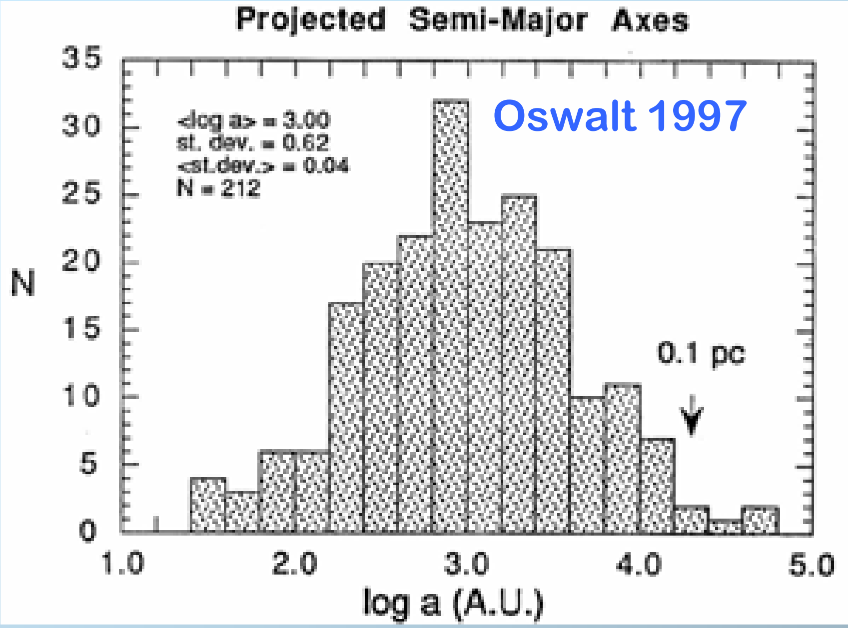


Most common type of binary? (6124 found by Luyten)

Common proper motion, no detectible orbital motion

Coeval, (barely) gravitationally-bound components

MS+MS Pairs



Physical classification of binary systems
(P = orbital period in years)

Extremely close binaries[a]	$P < 10^{-3}$
Very close binaries	$10^{-3} \lesssim P \lesssim 1$
Close binaries	$1 \lesssim P \lesssim 10$
Wide binaries	$10 \lesssim P \lesssim 10^2$
Very wide binaries	$10^2 \lesssim P \lesssim 10^3$
Extremely wide binaries[b]	$P > 10^3$

[a] Contact systems.
[b] CPM-systems.

Zinnecker 1984

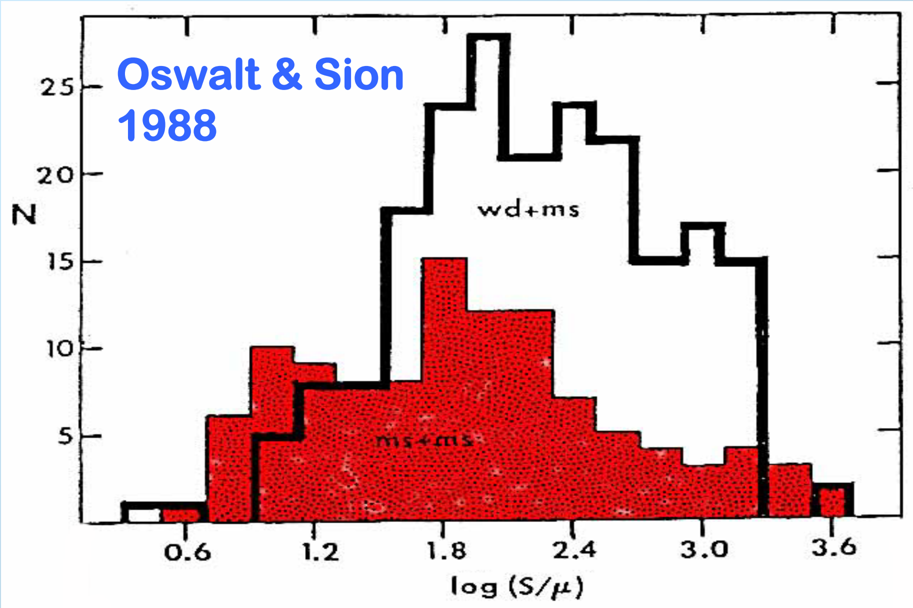
Different formation mechanisms?
Close: fragmentation vs. fission
Wide: capture vs. disintegration

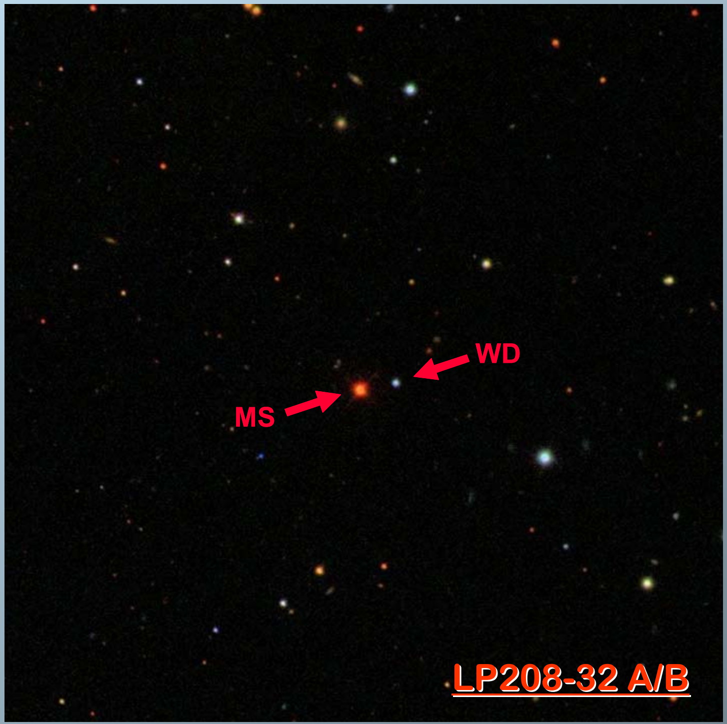
Main sequence pairs (>6000 known)

Most common type of binaries in Disk? Halo?
Sensitive to long-term Galactic perturbations

See Allen, Chanamé, Gavras, Kiyaeva, Poveda 2006;
New surveys: Chanamé & Gould 2004, Lépine & Shara 2005

MS+WD Pairs





Binaries with at least one evolved star (>1000 known)

MS "benchmark" for V_r, UVW, metallicity

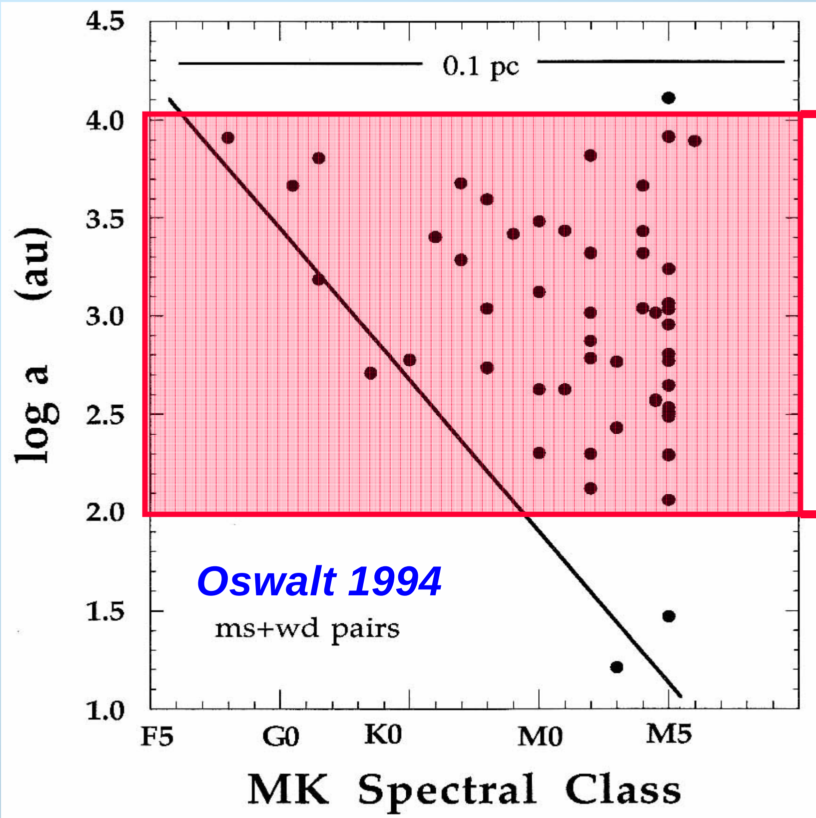
WD "benchmark" for age

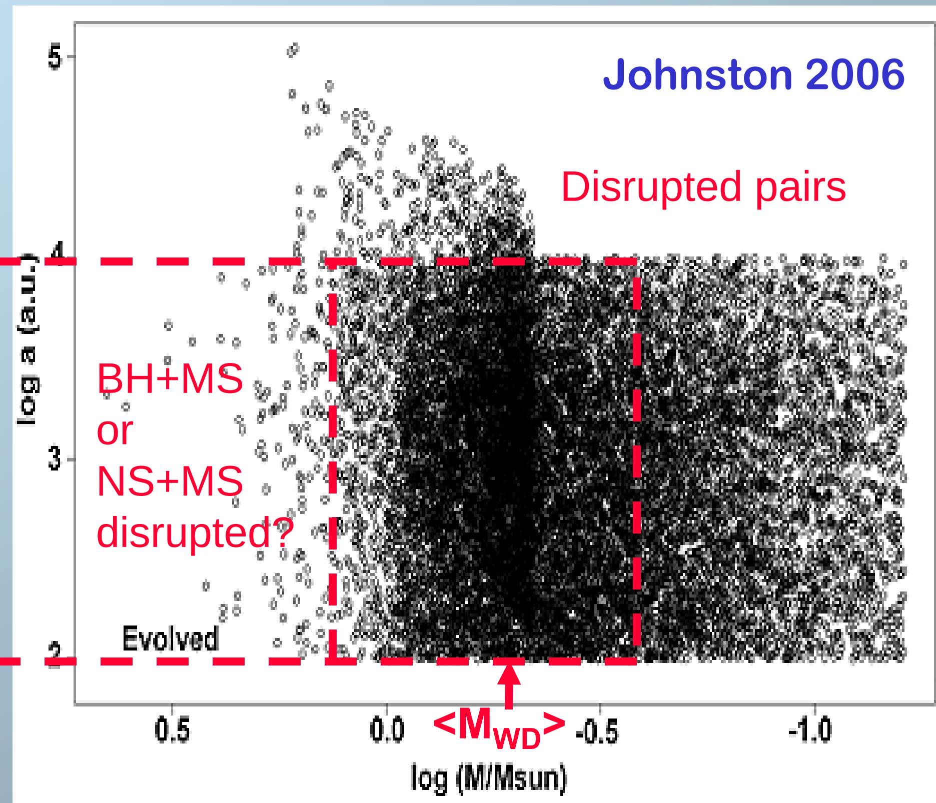
Test of post-MS mass loss & orbit evolution

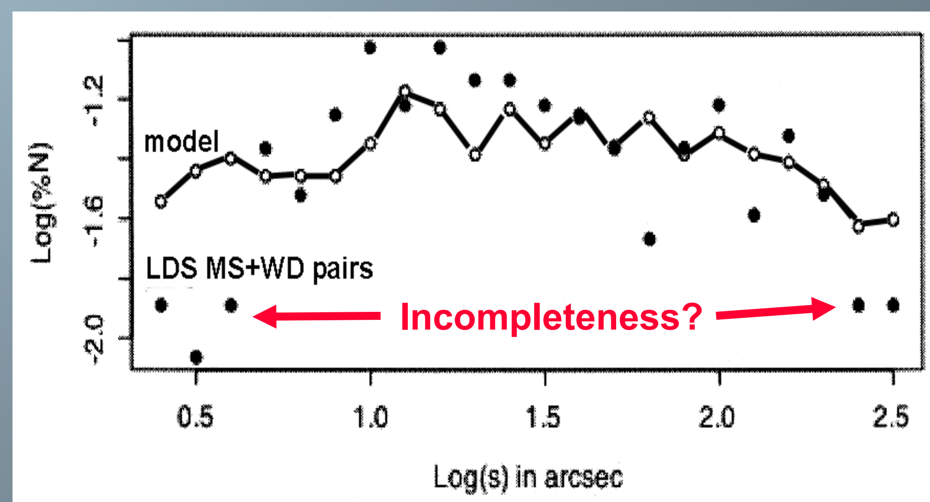
WD initial-final mass relation (IFMR)

See Johnston, Catalan 2006

Orbits - comparisons

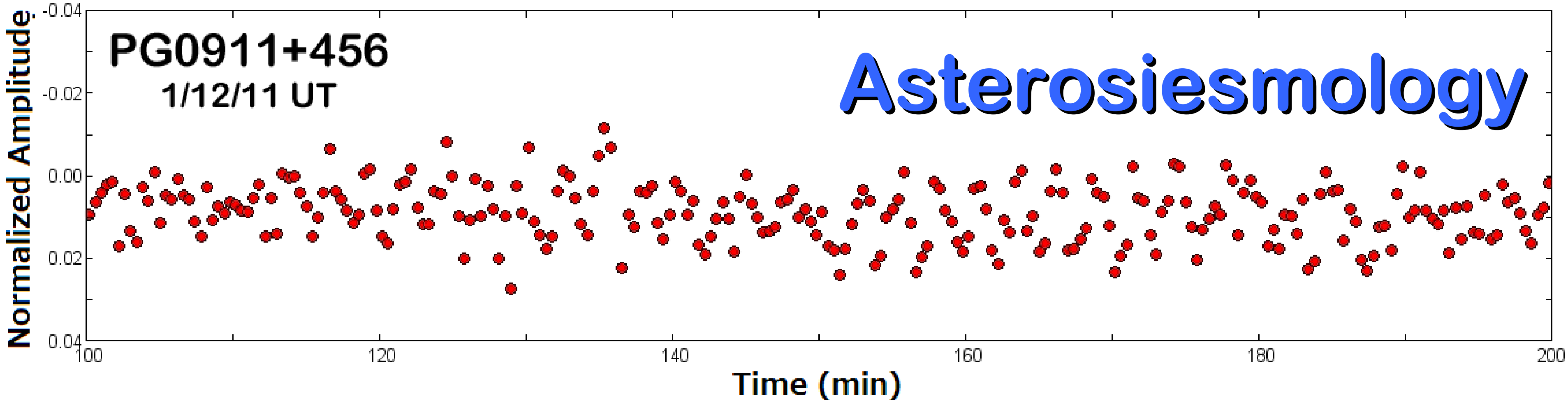




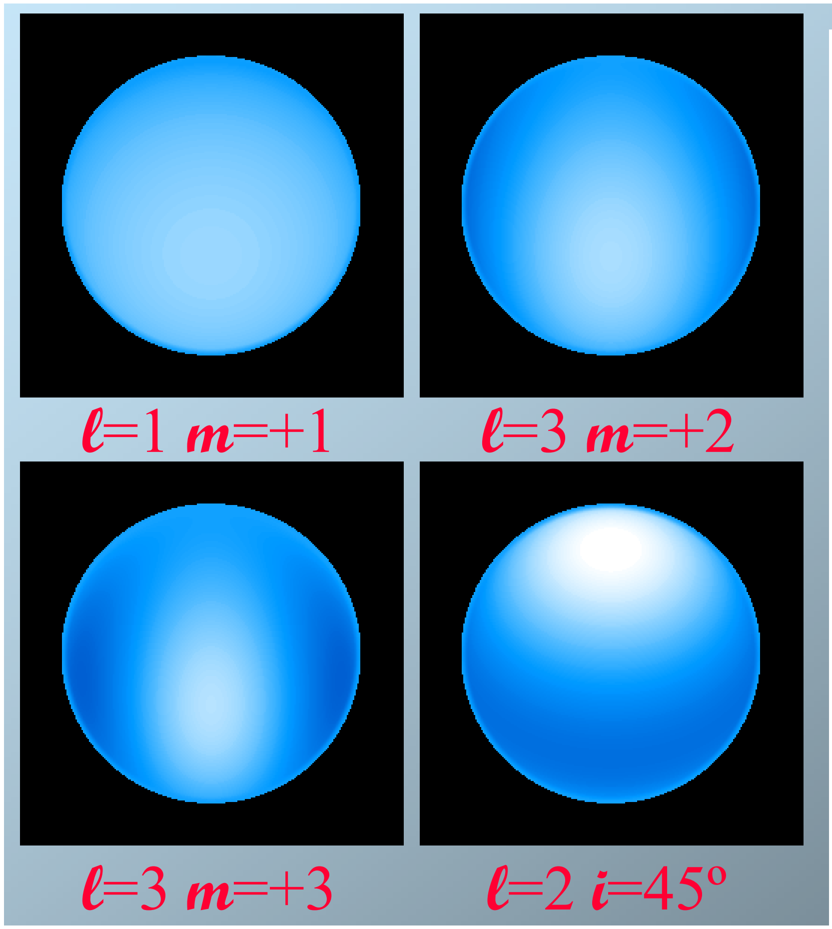


Orbit evolution can only explain
~ 1/2 the increases seen
Lower SFR, especially recently?
Wider $a(t_o)$ for high mass binaries?

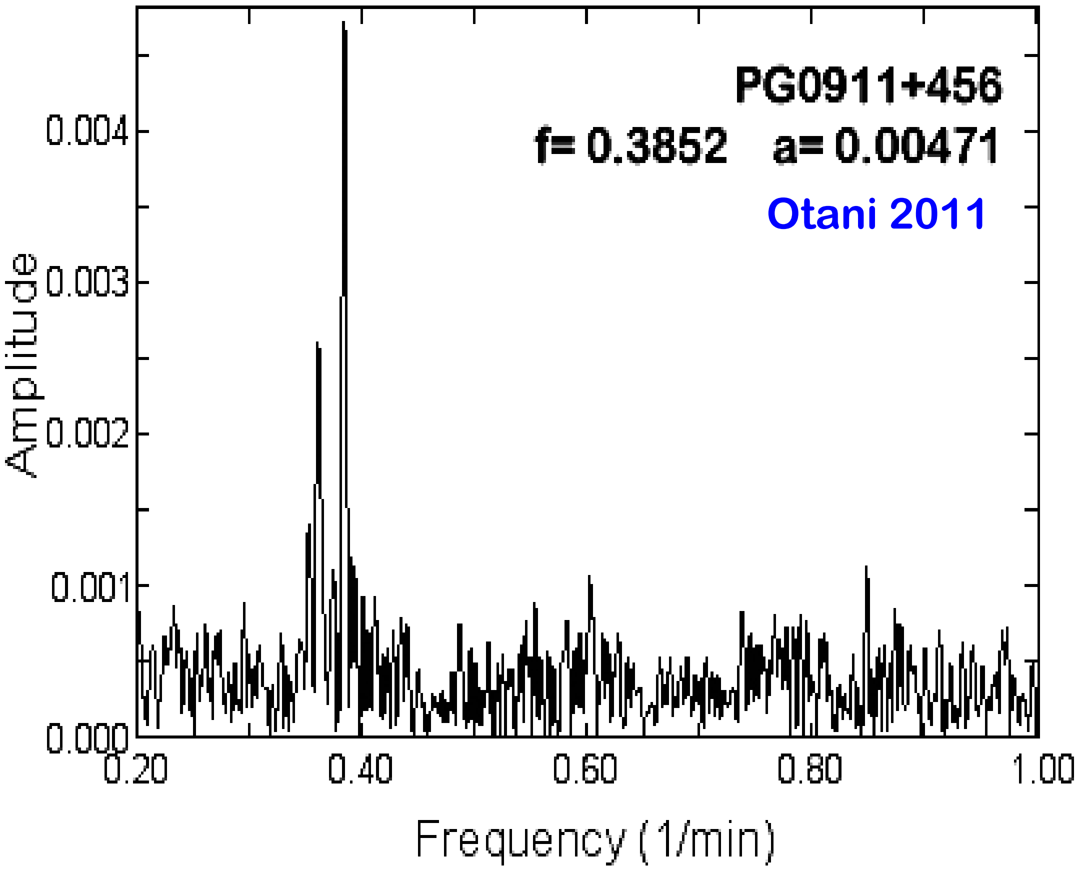

www.saraobservatory.org
SARA-N 1.0-m
Kitt Peak, Arizona
FIT Ortega 0.8-m
Melbourne, FL
SARA-S 0.6-m
Cerro Tololo - Chile
©2005 Google



PG0911+456
1/12/11 UT
Asterosiesmology
Normalized Amplitude
-0.04
-0.02
0.00
0.02
0.04
100
120
140
160
180
200
Time (min)

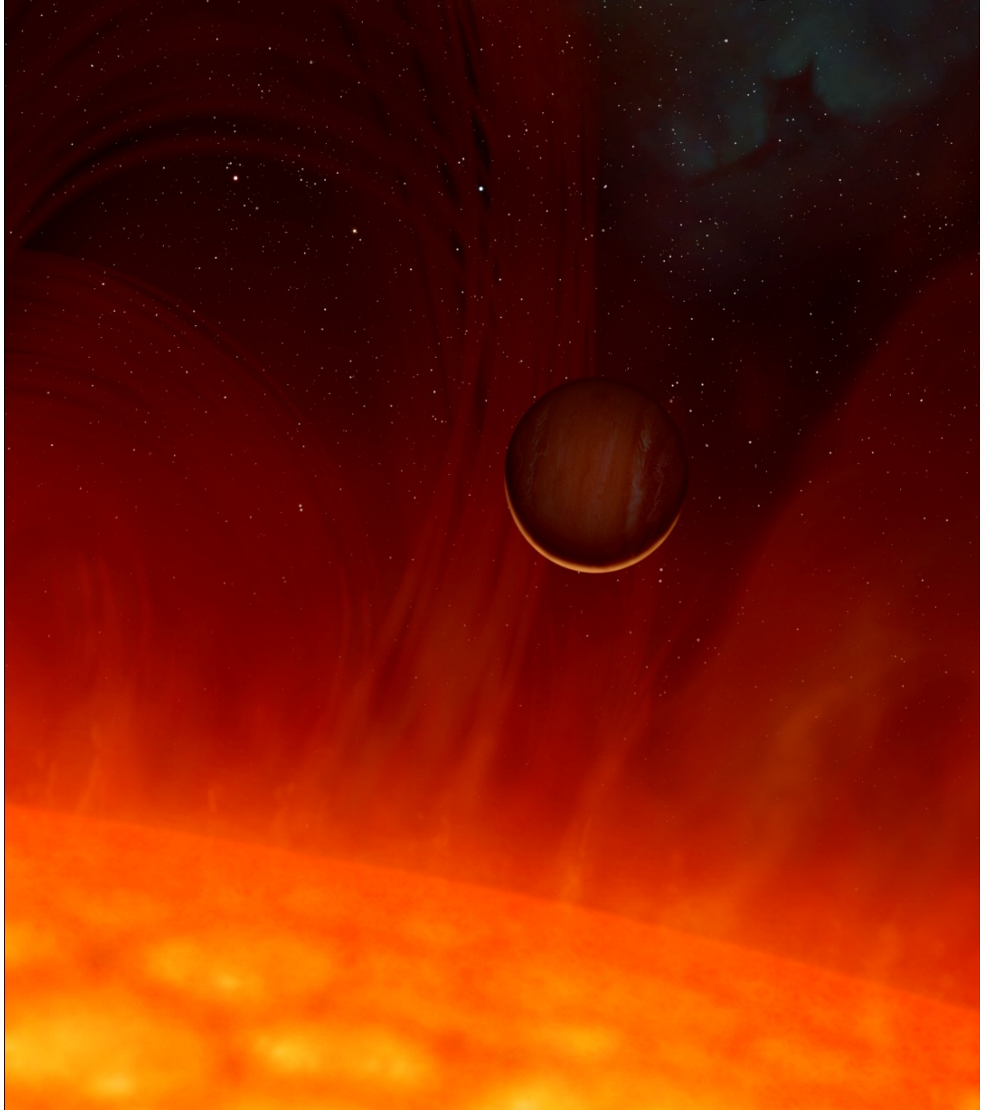


ℓ=1 m=+1
ℓ=3 m=+2
ℓ=3 m=+3
ℓ=2 i=45°

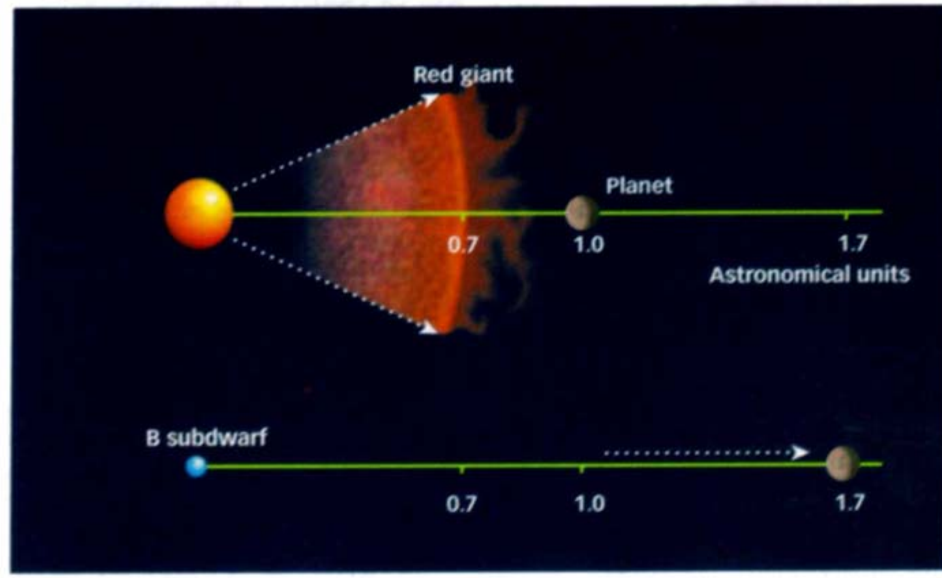


PG0911+456
f= 0.3852 a= 0.00471
Otani 2011
Amplitude
0.004
0.003
0.002
0.001
0.000
0.20
0.40
0.60
0.80
1.00
Frequency (1/min)

Detecting a Planetary "Survivor": V391 Pegasi b

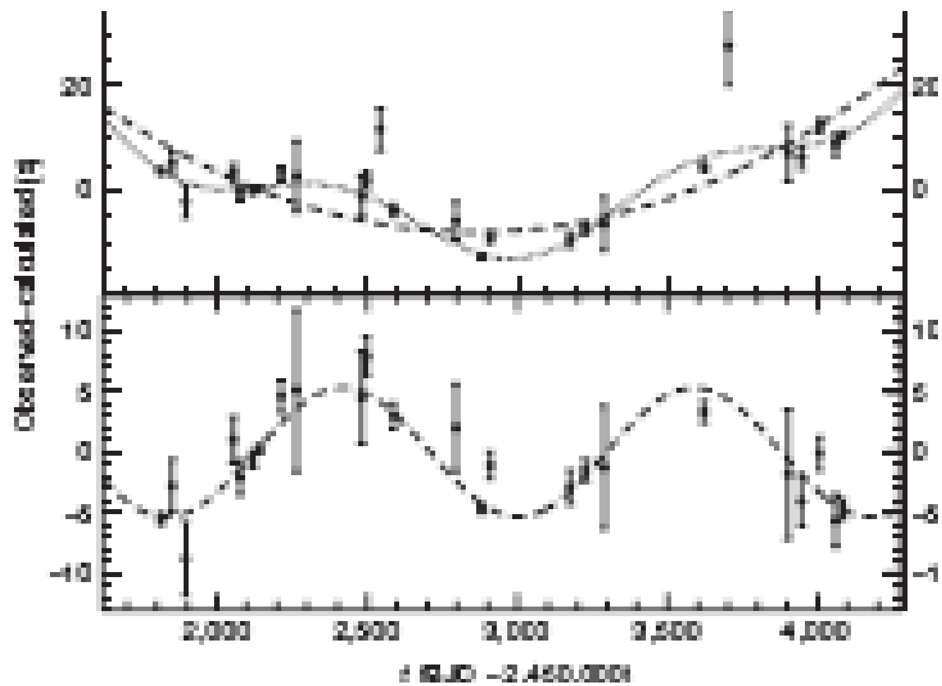


Silvotti et al. 2007

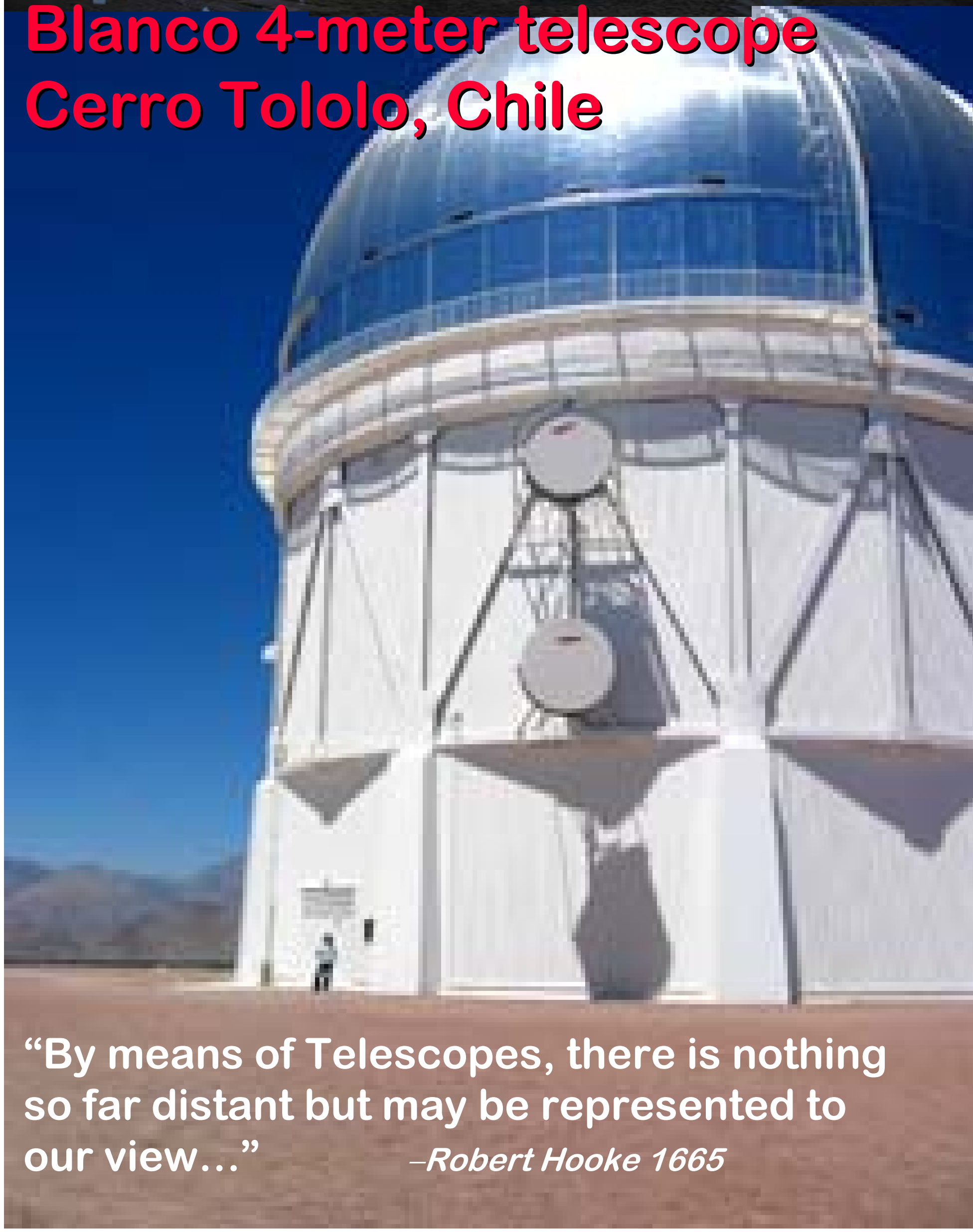


ENDURANCE A recently discovered planet has withstood the swelling of its aging parent star, which expanded nearly to 1 astronomical unit, the size of Earth's orbit (top). The star has since shrunk, and the planet has migrated about 70 percent farther from its parent (bottom).

Science News SEPTEMBER 15, 2007 VOL. 172 163



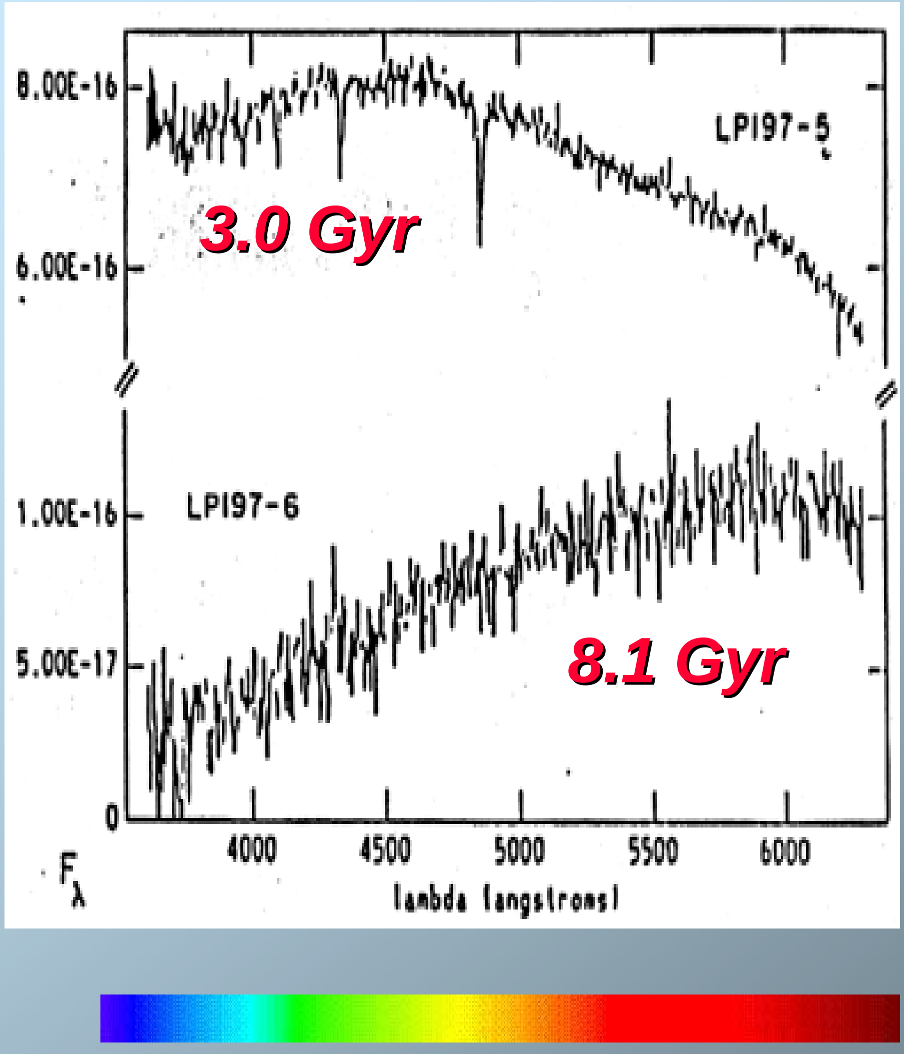
Blanco 4-meter telescope
Cerro Tololo, Chile

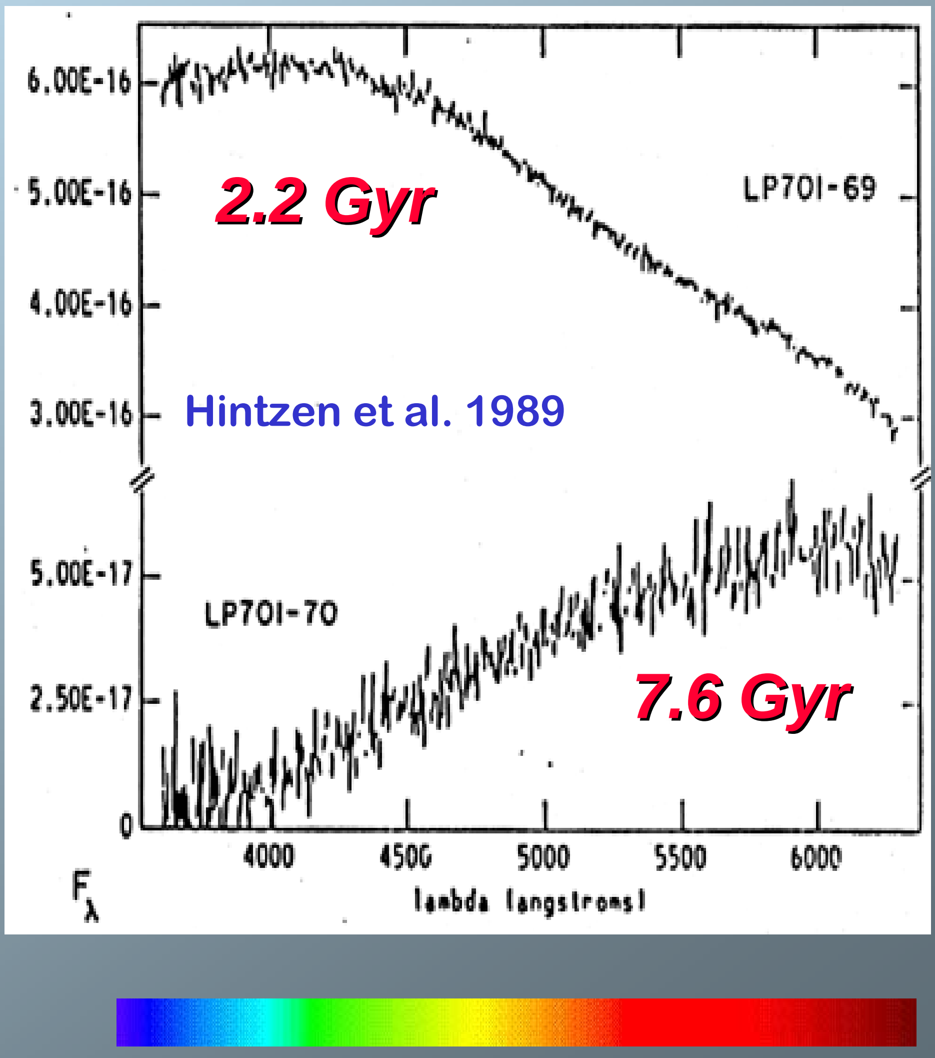


"By means of Telescopes, there is nothing so far distant but may be represented to our view…" *–Robert Hooke 1665*

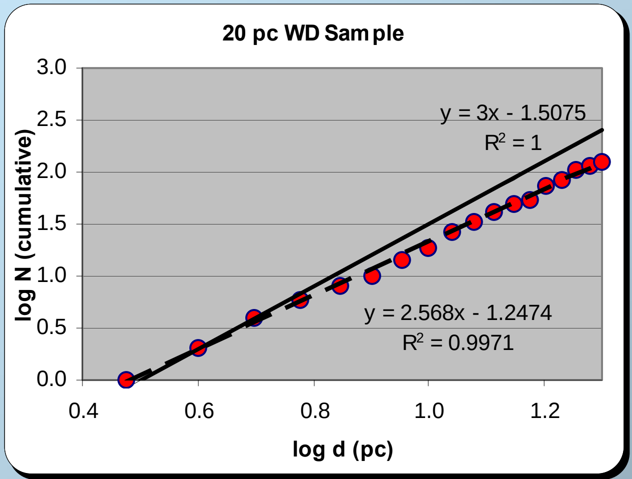
First Spectra of Cool Old White Dwarfs

1 Gyr = 1,000,000,000 yr



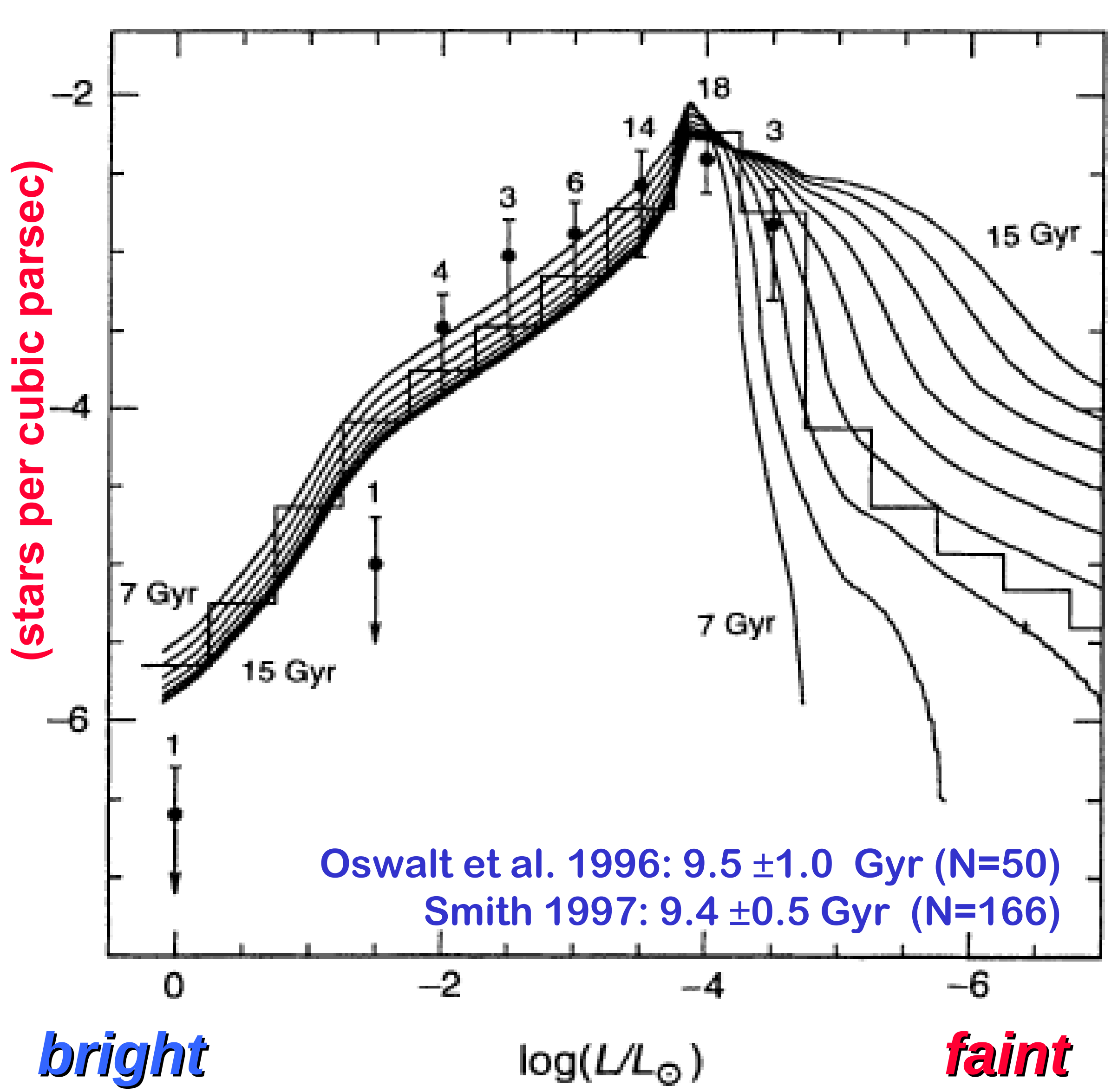


How Common are White Dwarfs? How Old is the Galaxy?



126 WDs within 20 pc
Sample complete to 4pc
$7.4 \pm 0.7 \times 10^{-3}$ pc^{-3}
$\rightarrow 135$ pc^3 for 1 WD

Holberg, Oswalt & Sion 2011

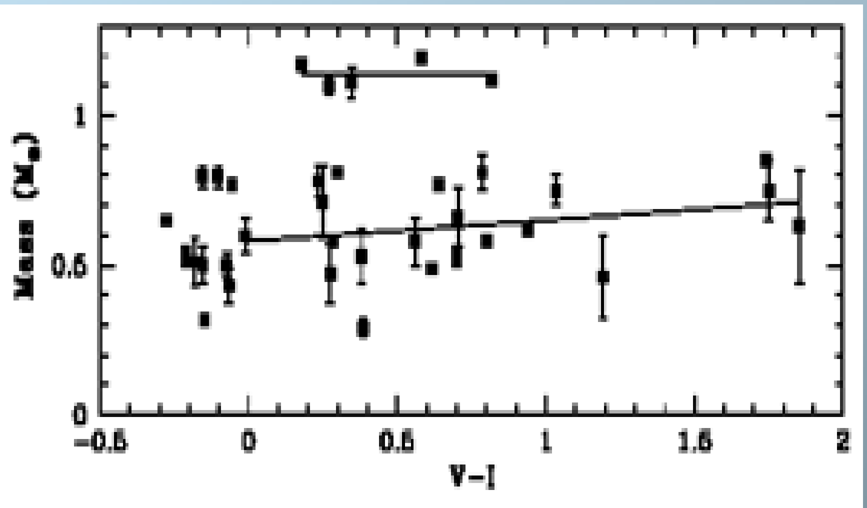


WD MASSES: Gravitational Redshifts

$V_{orb} < 1$ km/s

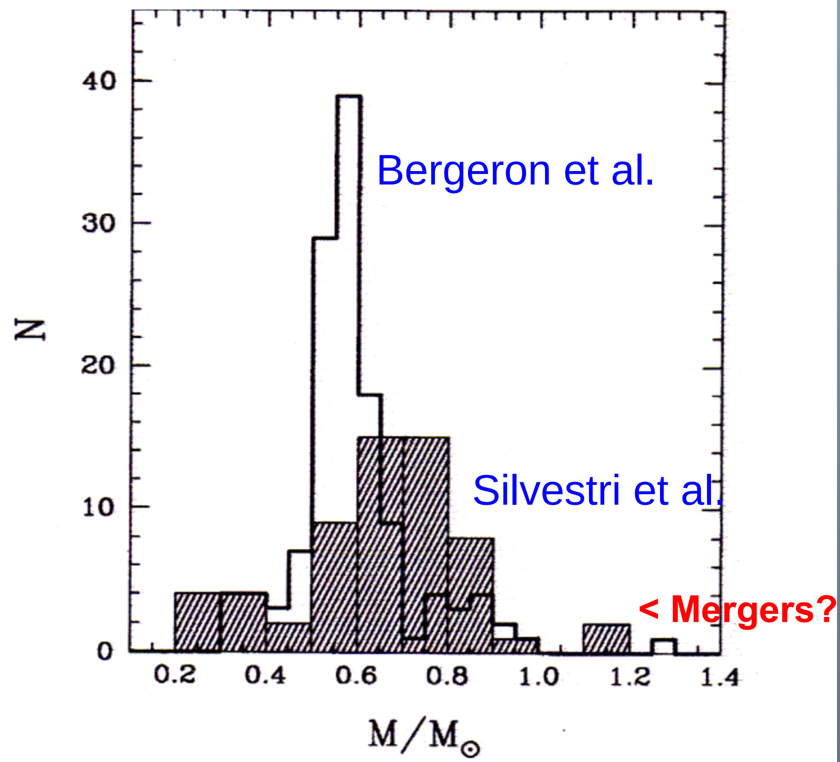
$V_{rs} \approx V_{rad}(WD) - V_{rad}(MS)$

$V_{rs} \sim M / R$

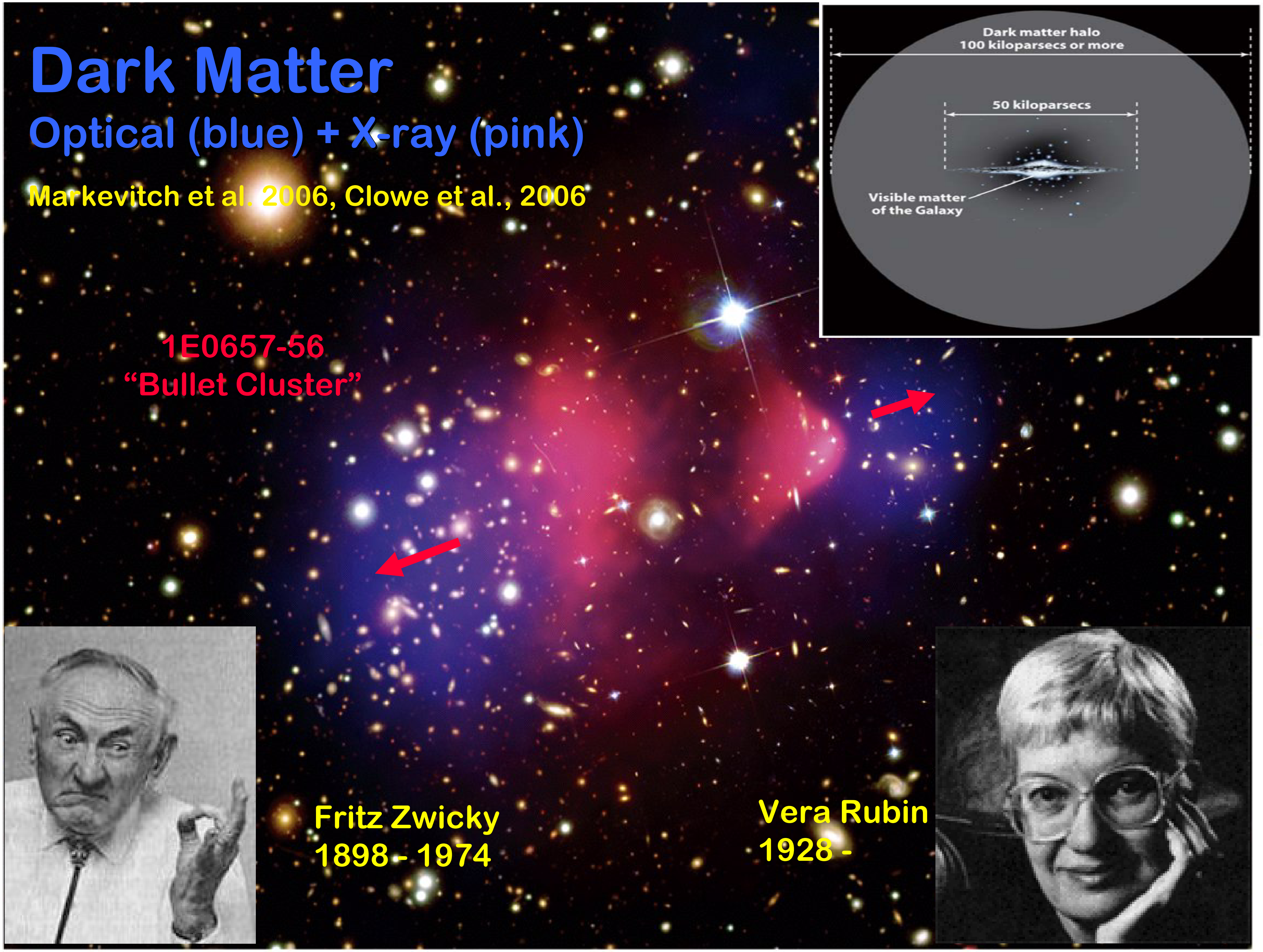


Silvestri et al. 2001

THE WD MASS DISTRIBUTION

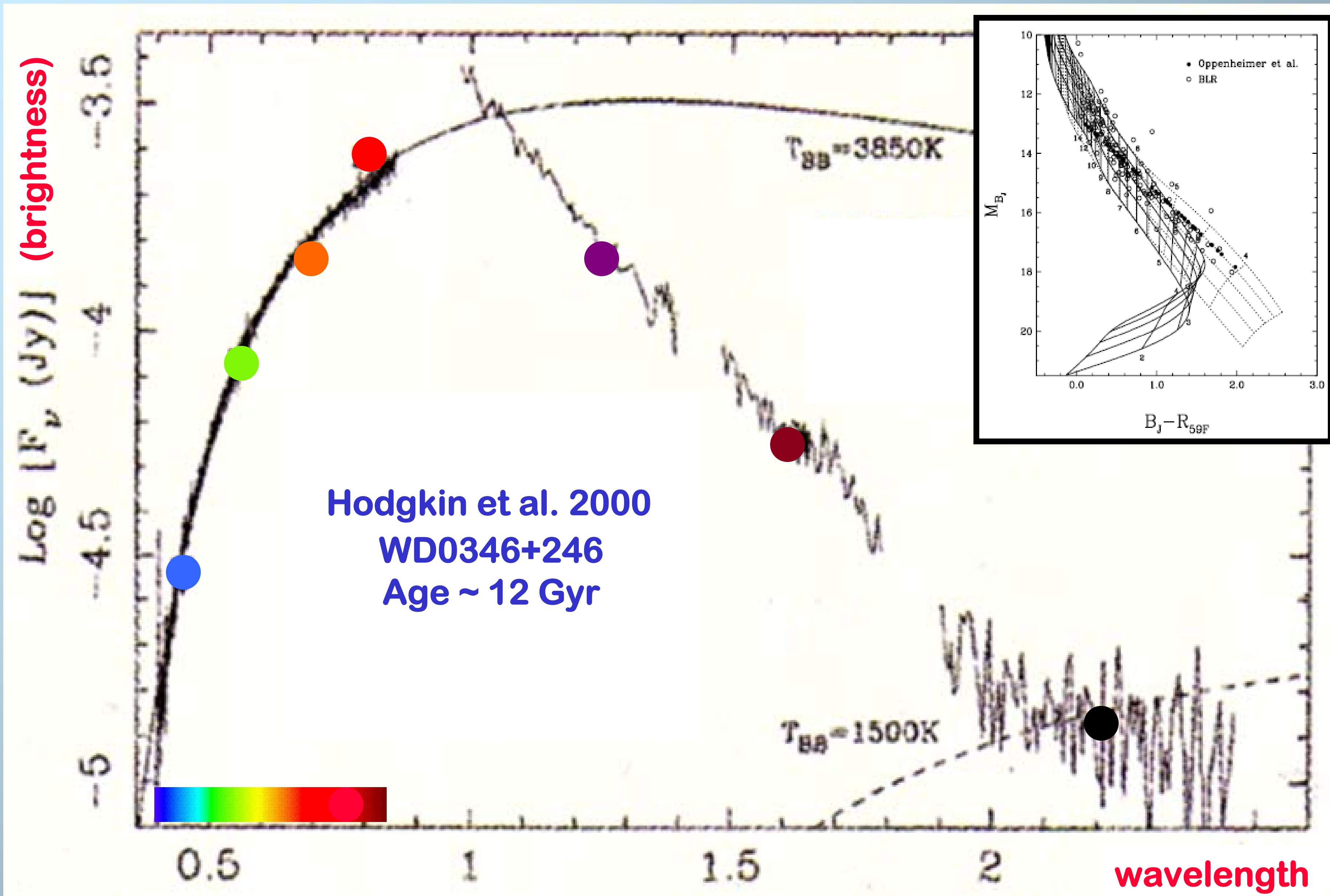


Comparison of spectroscopically determined masses for hot H-rich WDs (no shading; <M> ~ 0.59 +/- 013 M_{sun}) and cool T_{eff} < 6000K WDs (shaded; <M> ~ 0.66 +/- 019 M_{sun})


Dark Matter
Optical (blue) + X-ray (pink)
Markevitch et al. 2006, Clowe et al., 2006
Dark matter halo
100 kiloparsecs or more
50 kiloparsecs
Visible matter
of the Galaxy
1E0657-56
"Bullet Cluster"
Fritz Zwicky
1898 - 1974
Vera Rubin
1928 -

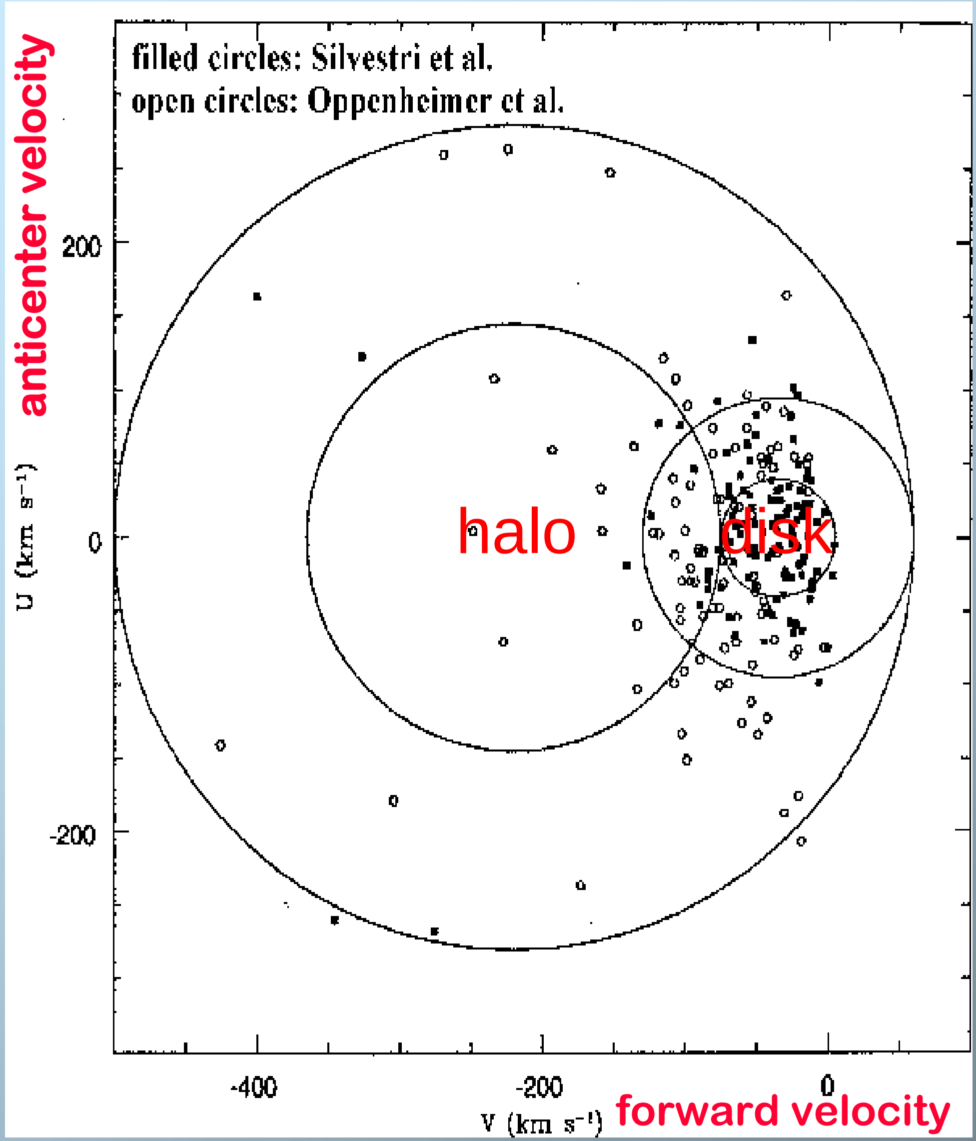
"Cool Blue WDs"

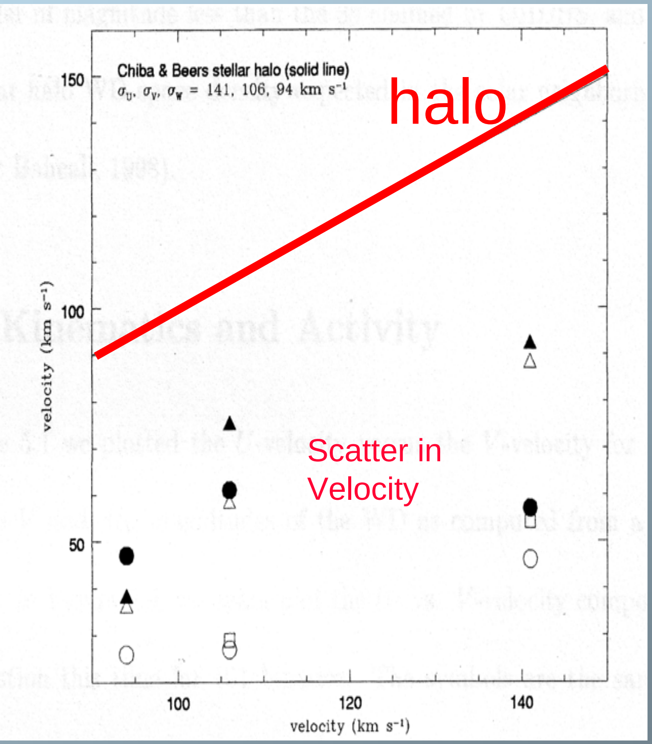
Sauman & Jabobsen 1999



White Dwarfs & Dark Matter - NOT

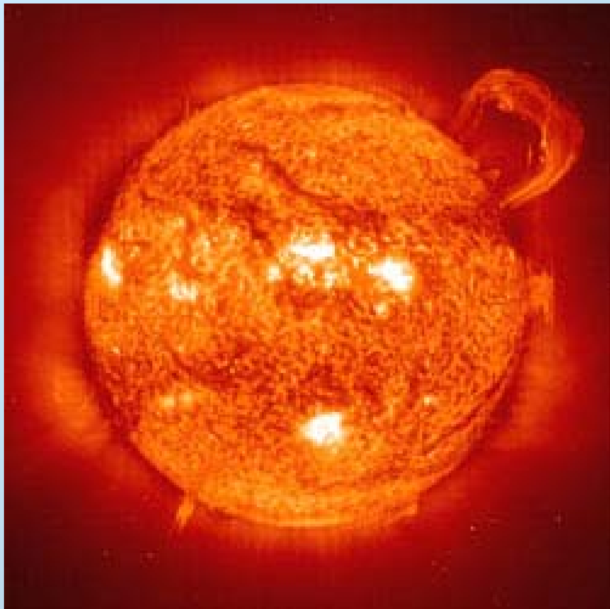
Silvestri, Oswalt, Hawley 2002

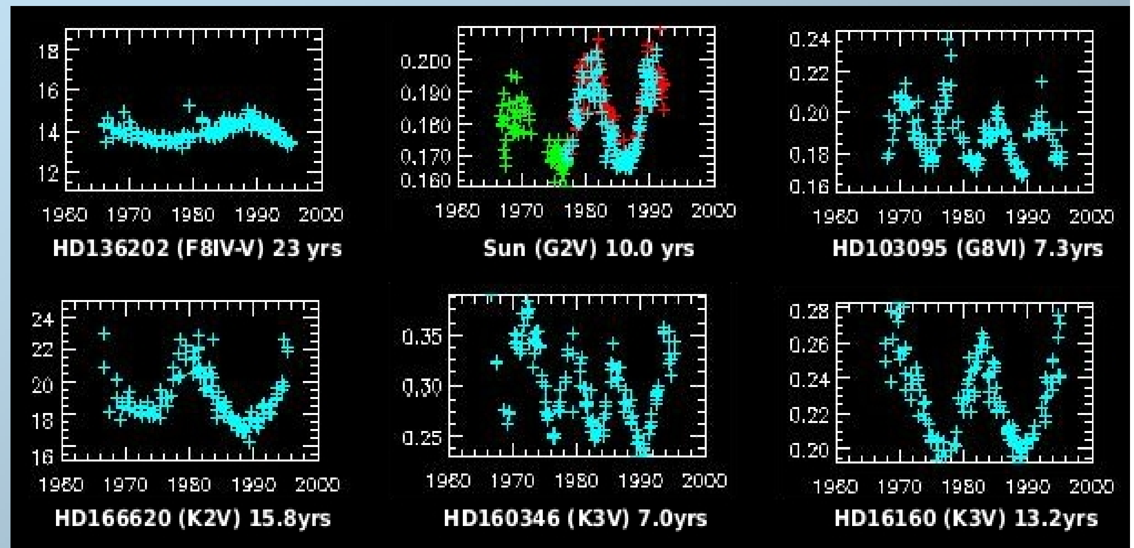


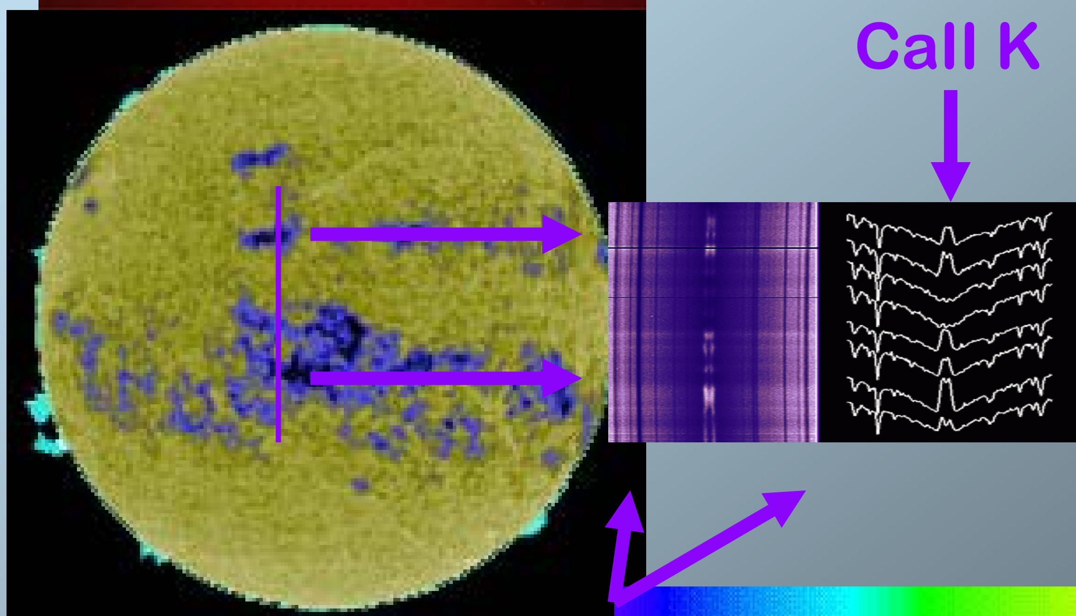


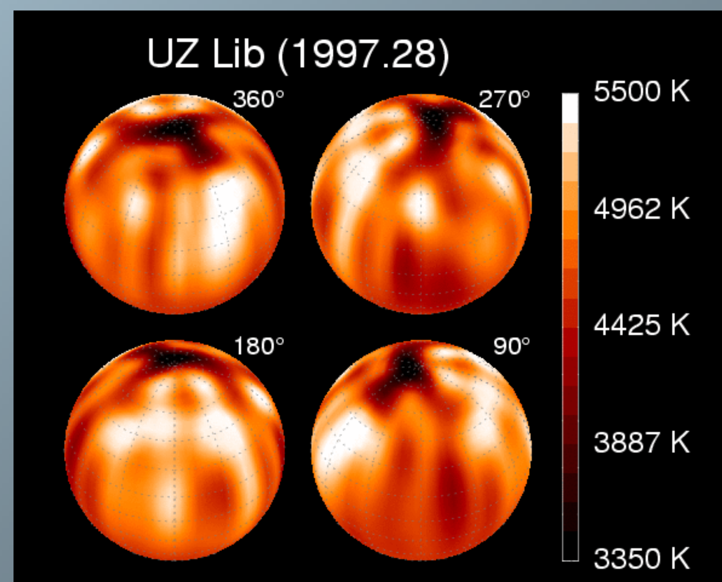
Stellar Activity

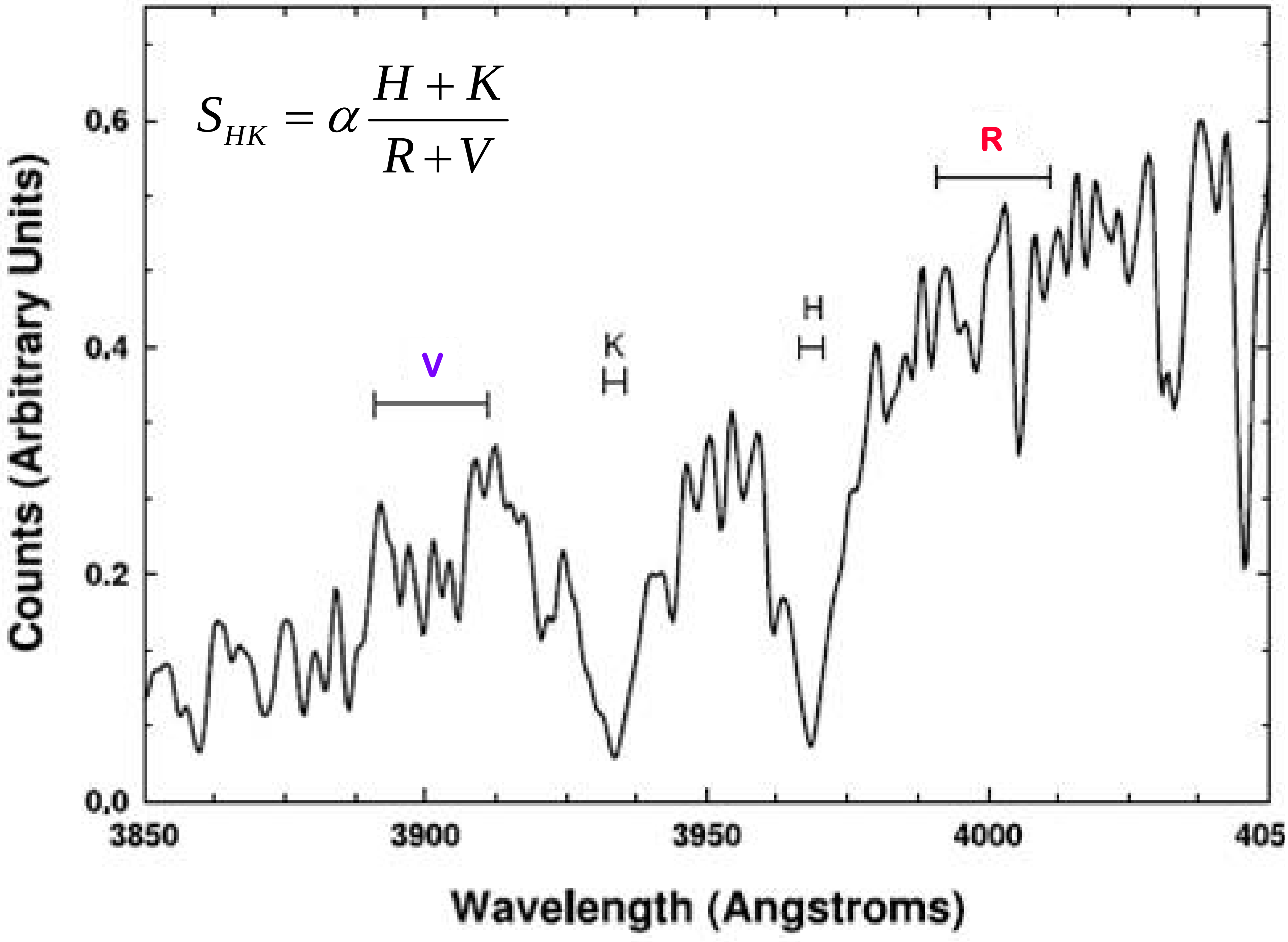
www.mtwilson.edu/hk/overview





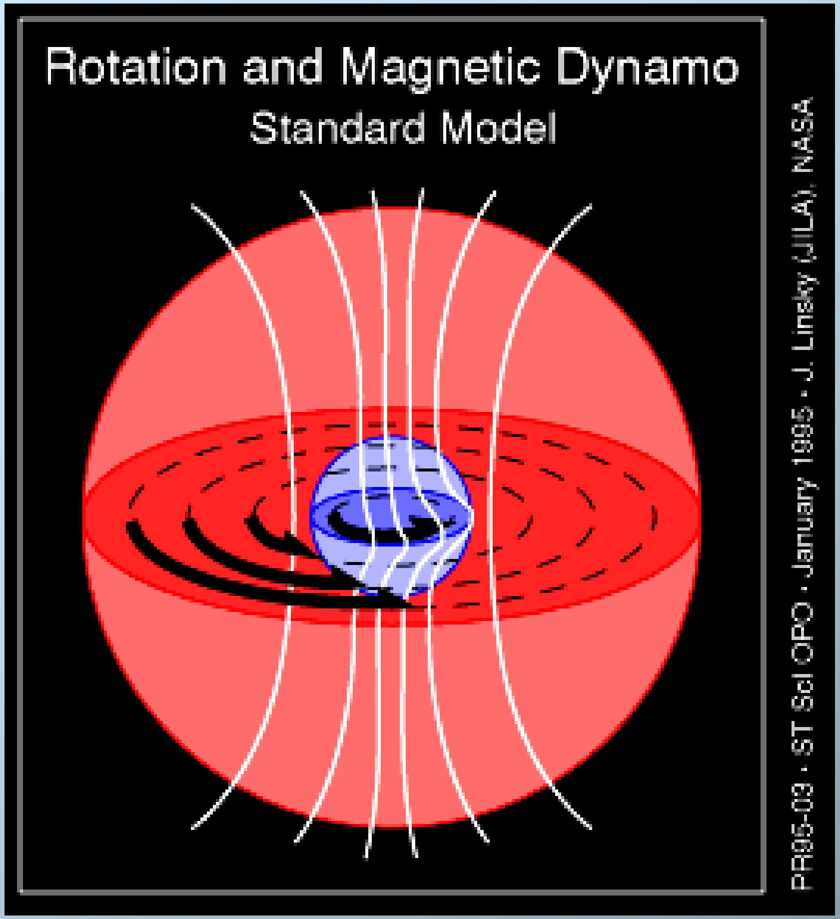


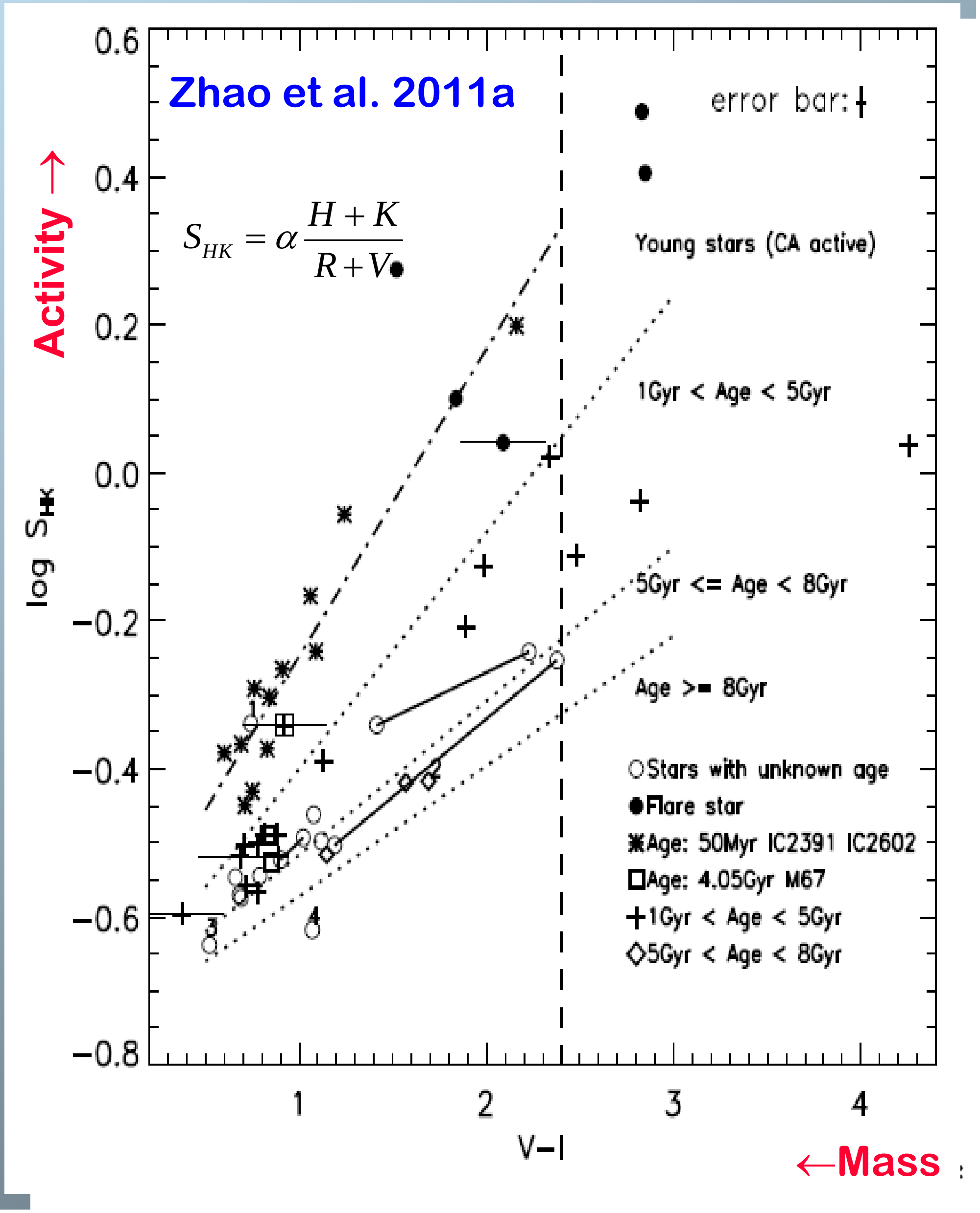




$S_{HK} = \alpha \frac{H+K}{R+V}$
R
V
K
H
Counts (Arbitrary Units)
0.0
0.2
0.4
0.6
3850
3900
3950
4000
405
Wavelength (Angstroms)

Stellar Activity vs. Age

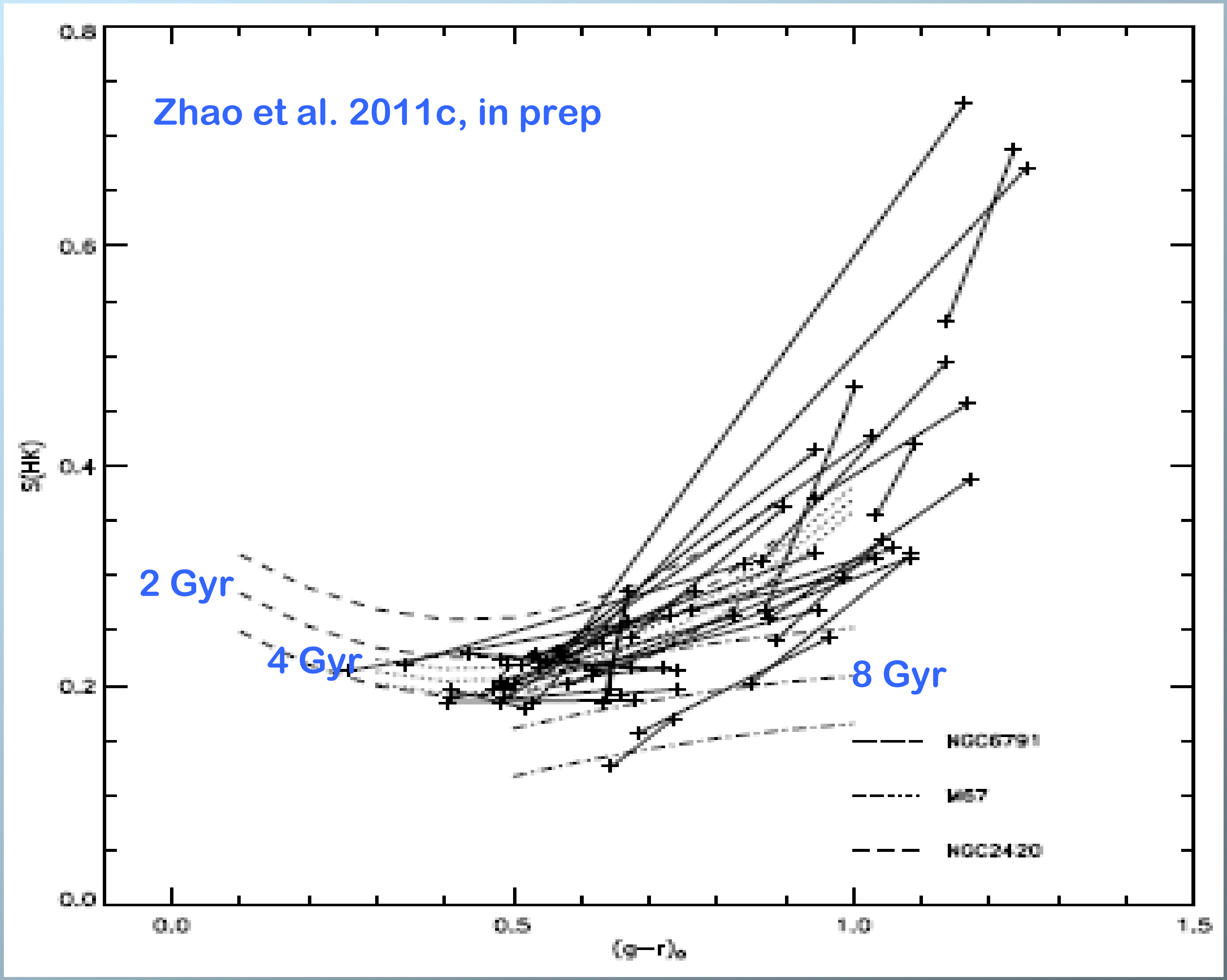




Like people, stars get less active as they get older!

Chromospheric Activity in MS Binaries

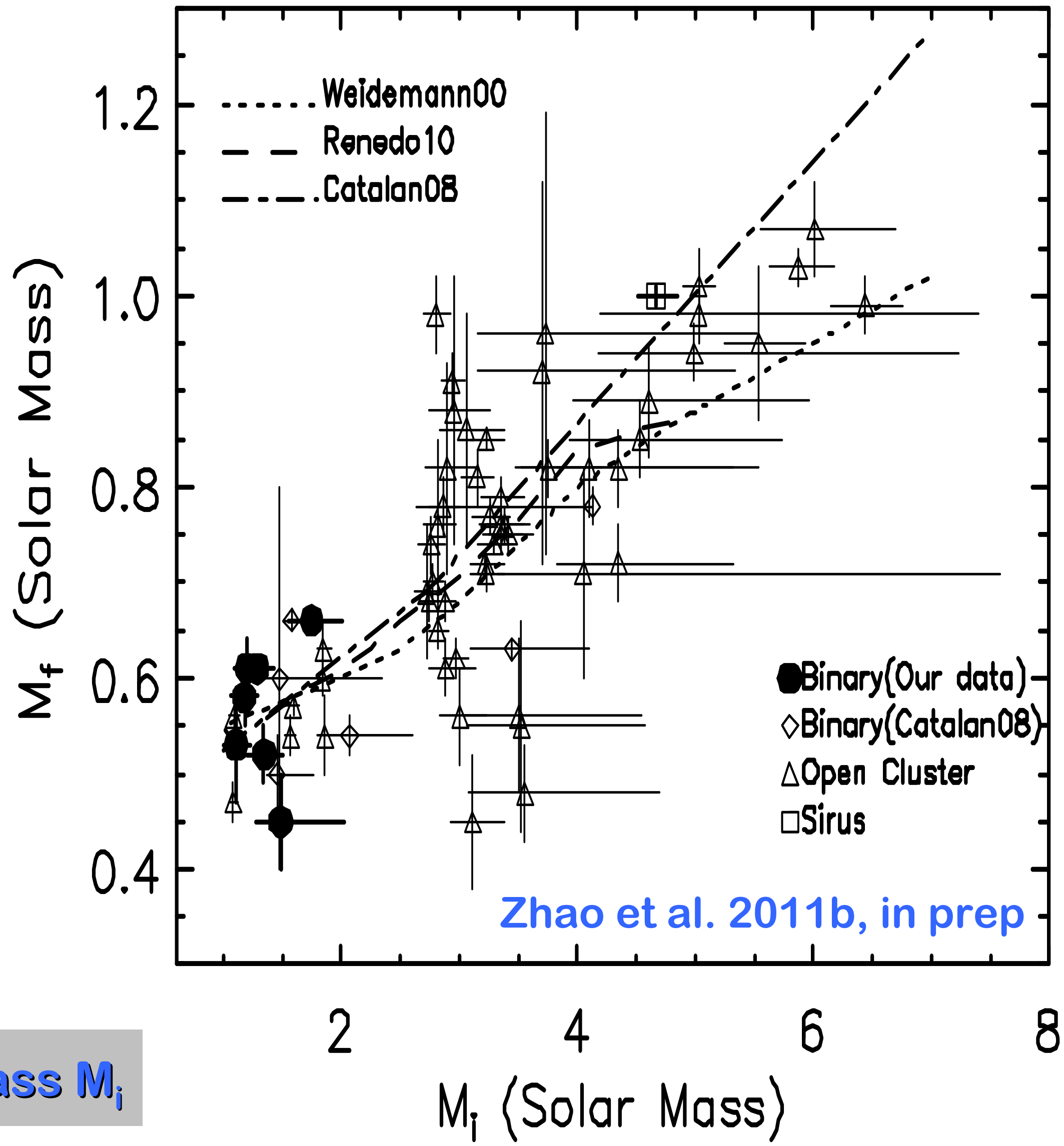
Testing the assumption of coevality using SDSS pairs



Mother Nature recycles…we're proof!

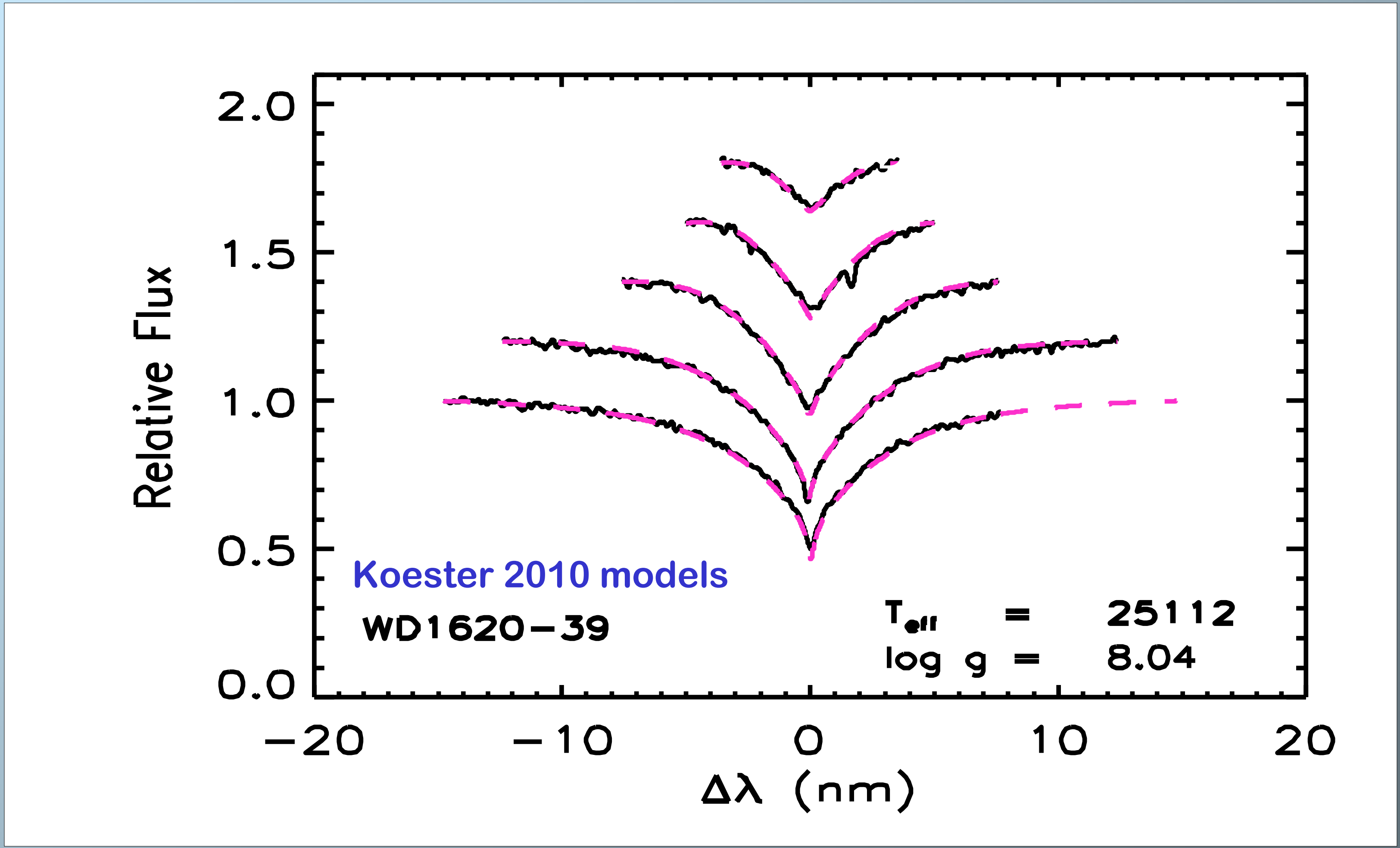
The WD Initial-to-Final Mass Relation

WD progenitor life → original mass M_i

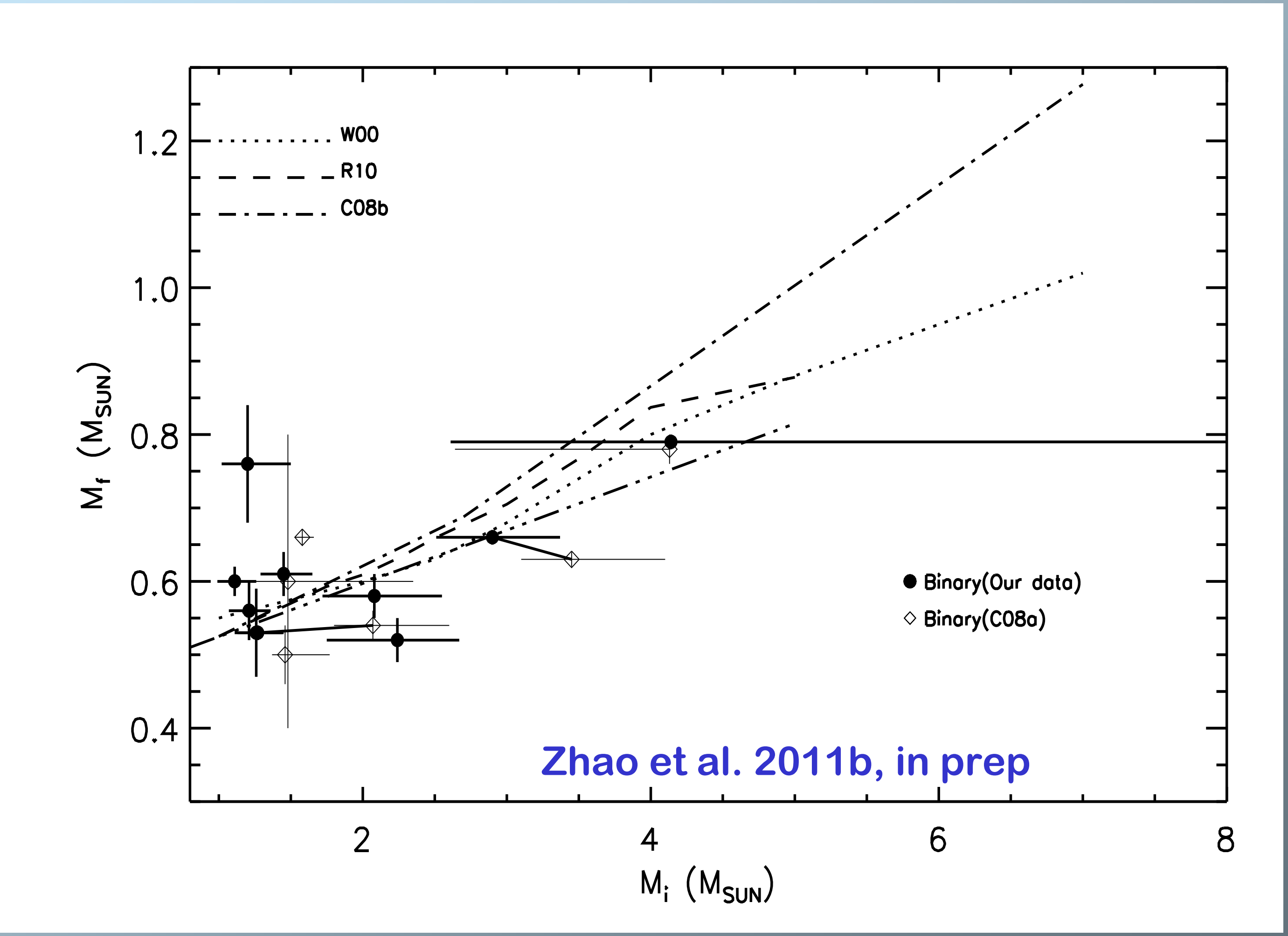


T_{eff} & log *g* of White Dwarf in a Binary

⇨ $t_{cool} = t_{ms} - t_{prog}$ (t_{prog} ⇨ M_i for WD)

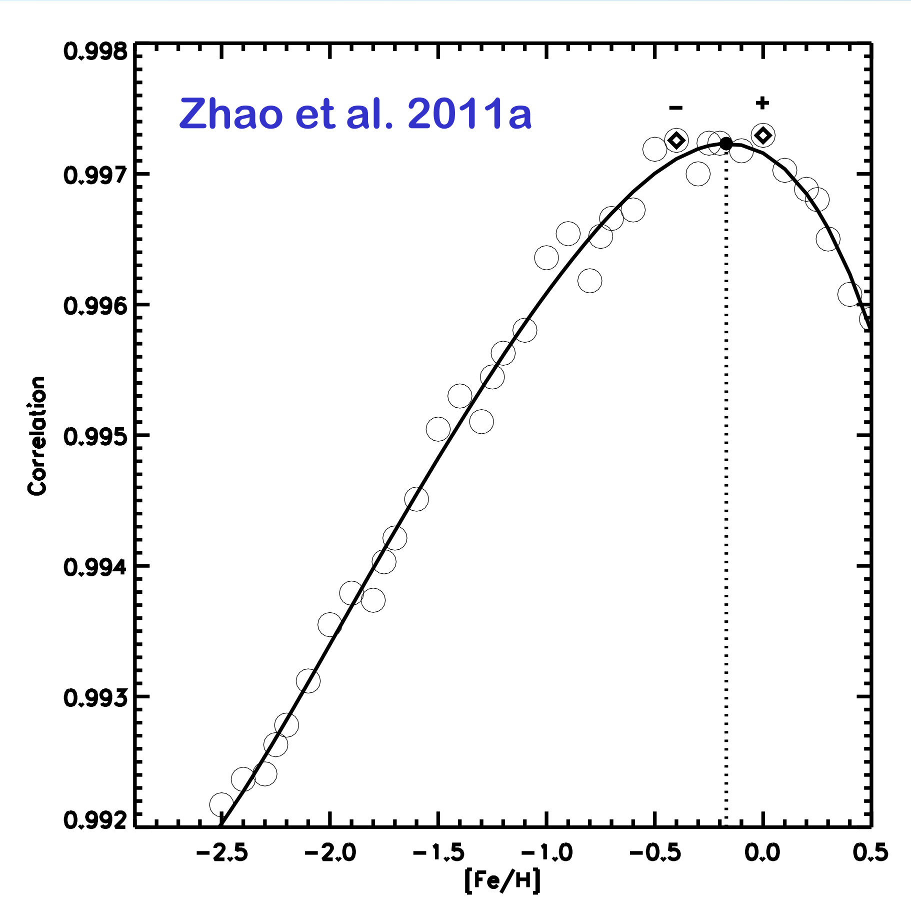


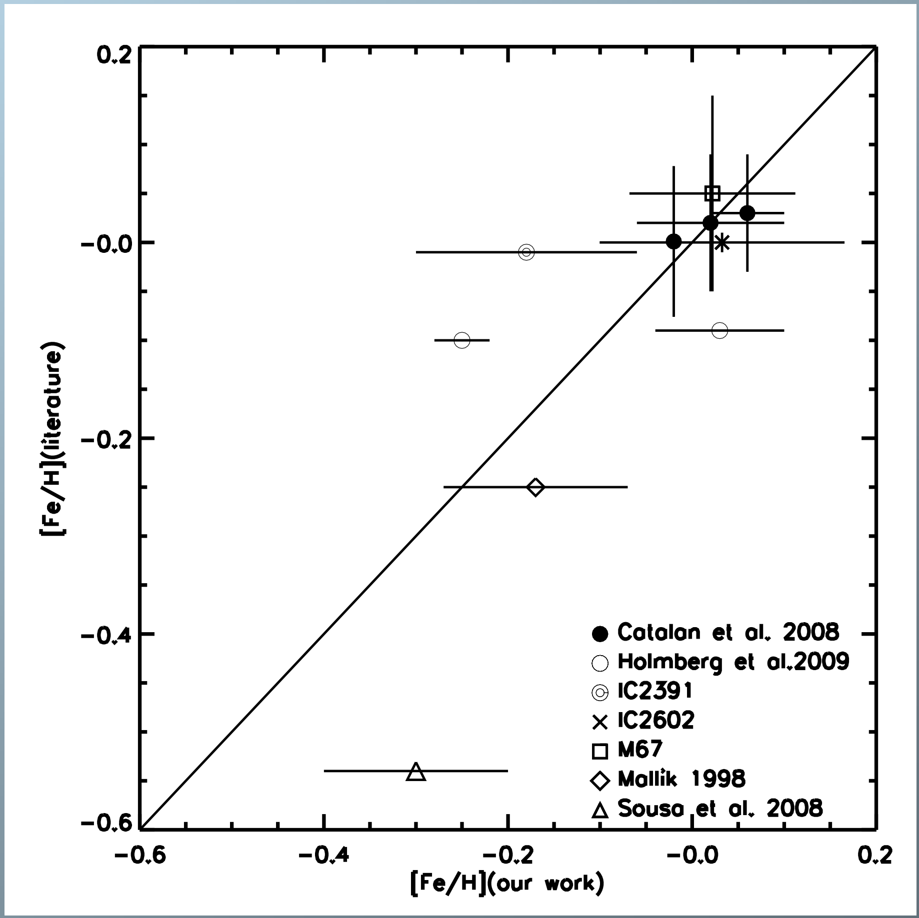
Initial-Final Mass Relation (IMFR) of White Dwarfs in Fragile Binaries



Metallicity of
Main Sequence Stars in Fragile Binaries

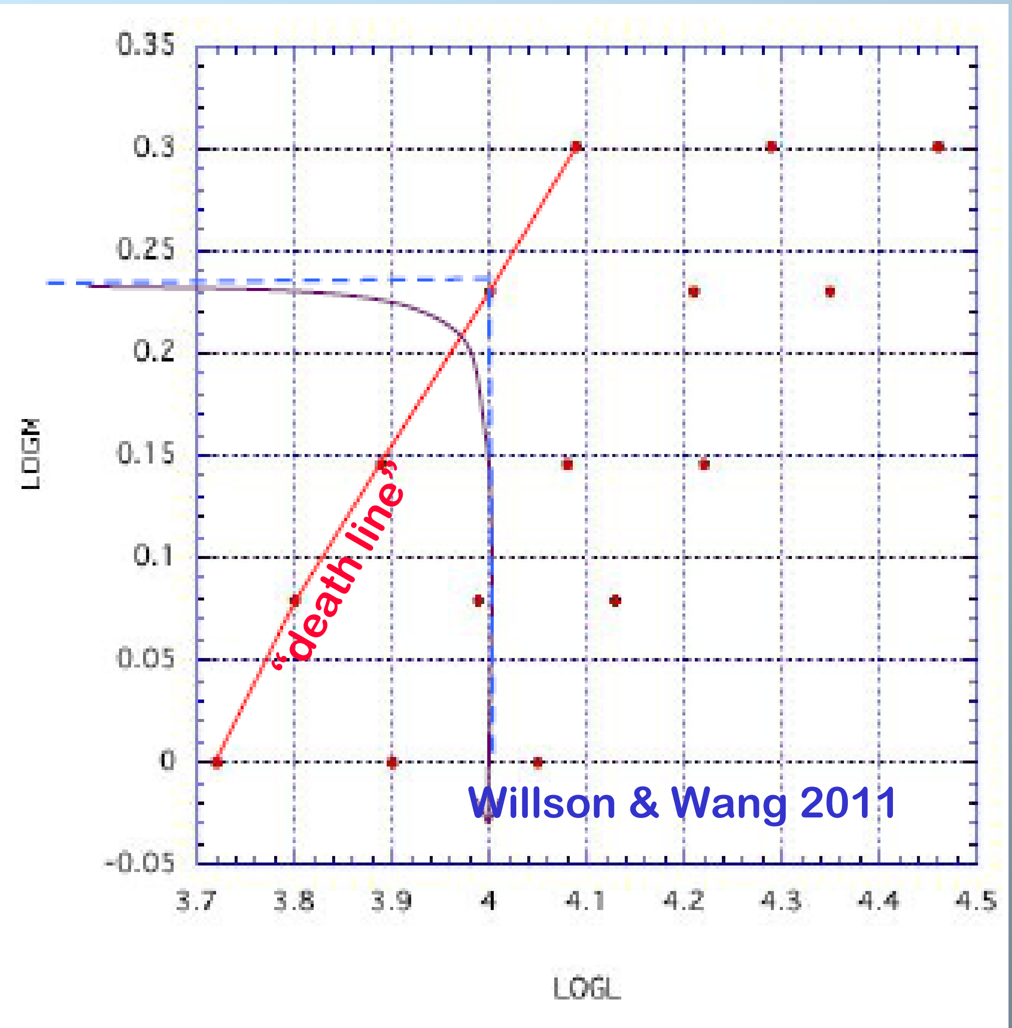
σ[Fe/H]=0.15 dex compared with the values from high resolution spectra

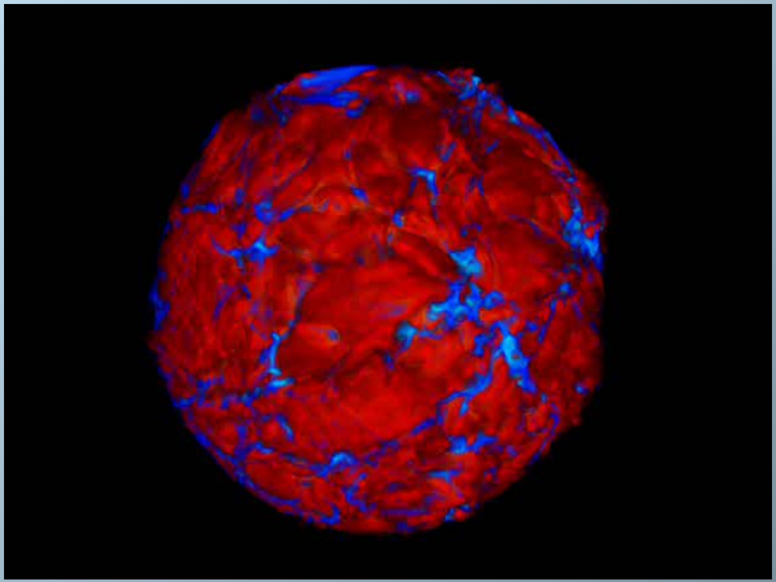




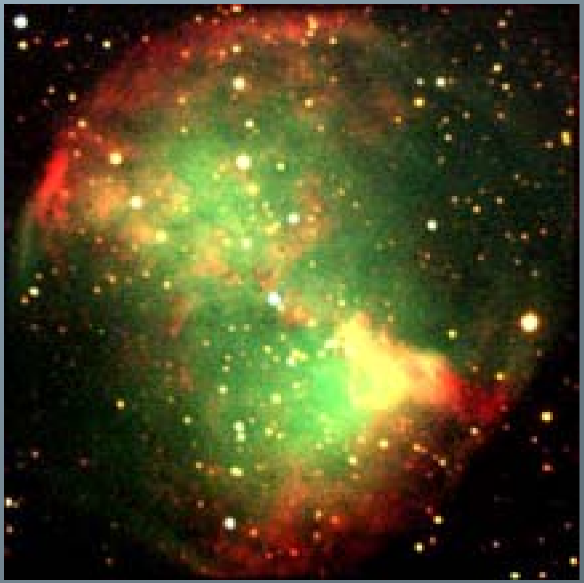
Maximum Correlation with theoretical spectra library of Castelli & Kurucz 2003

Post Main Sequence Pulsations & Mass Loss



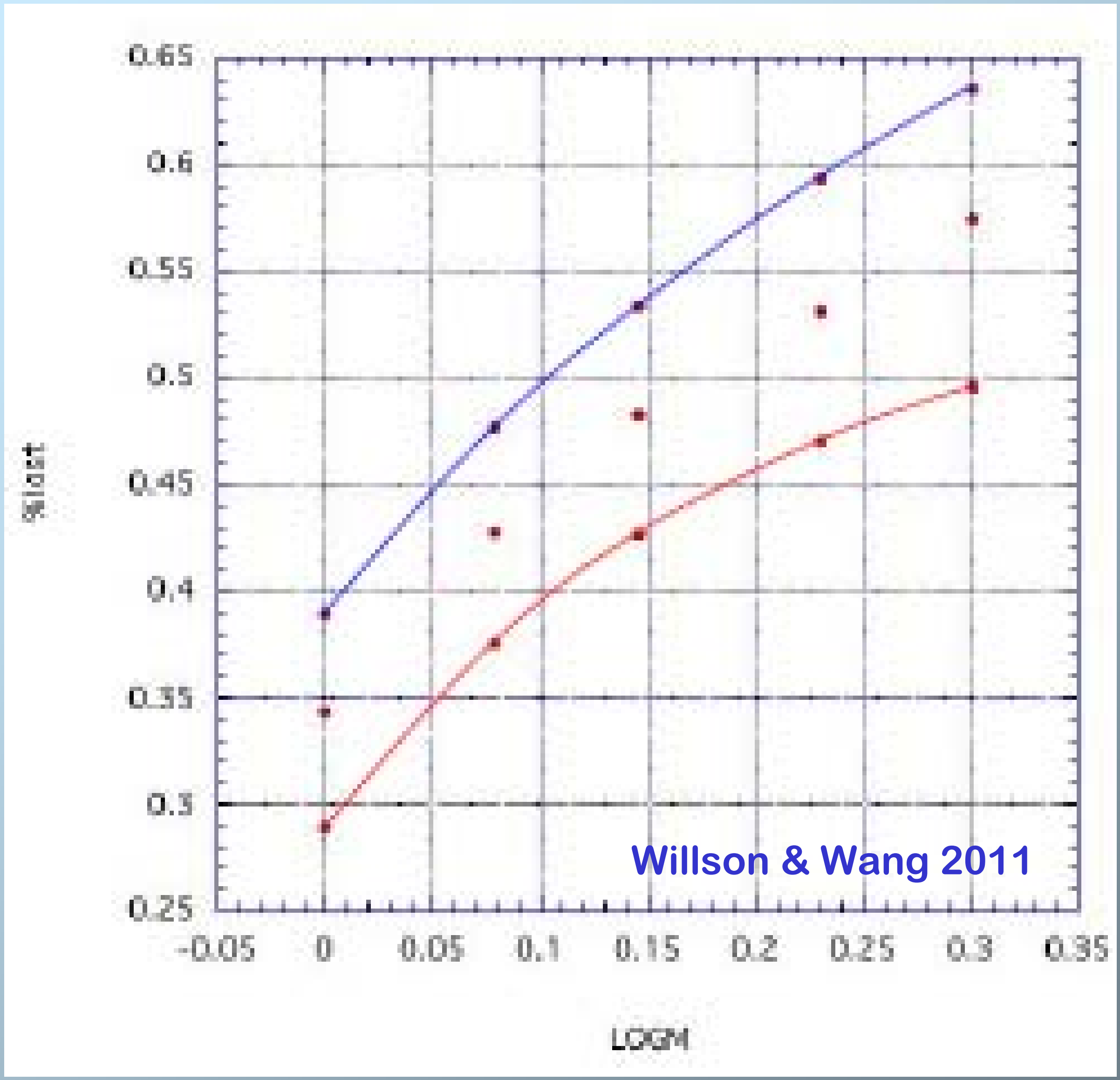


D. Porter, S. Anderson, P. Woodward
U. Minnesota



V. Wilkat, FIT/SARA

Metallicity and Post-MS Mass Loss

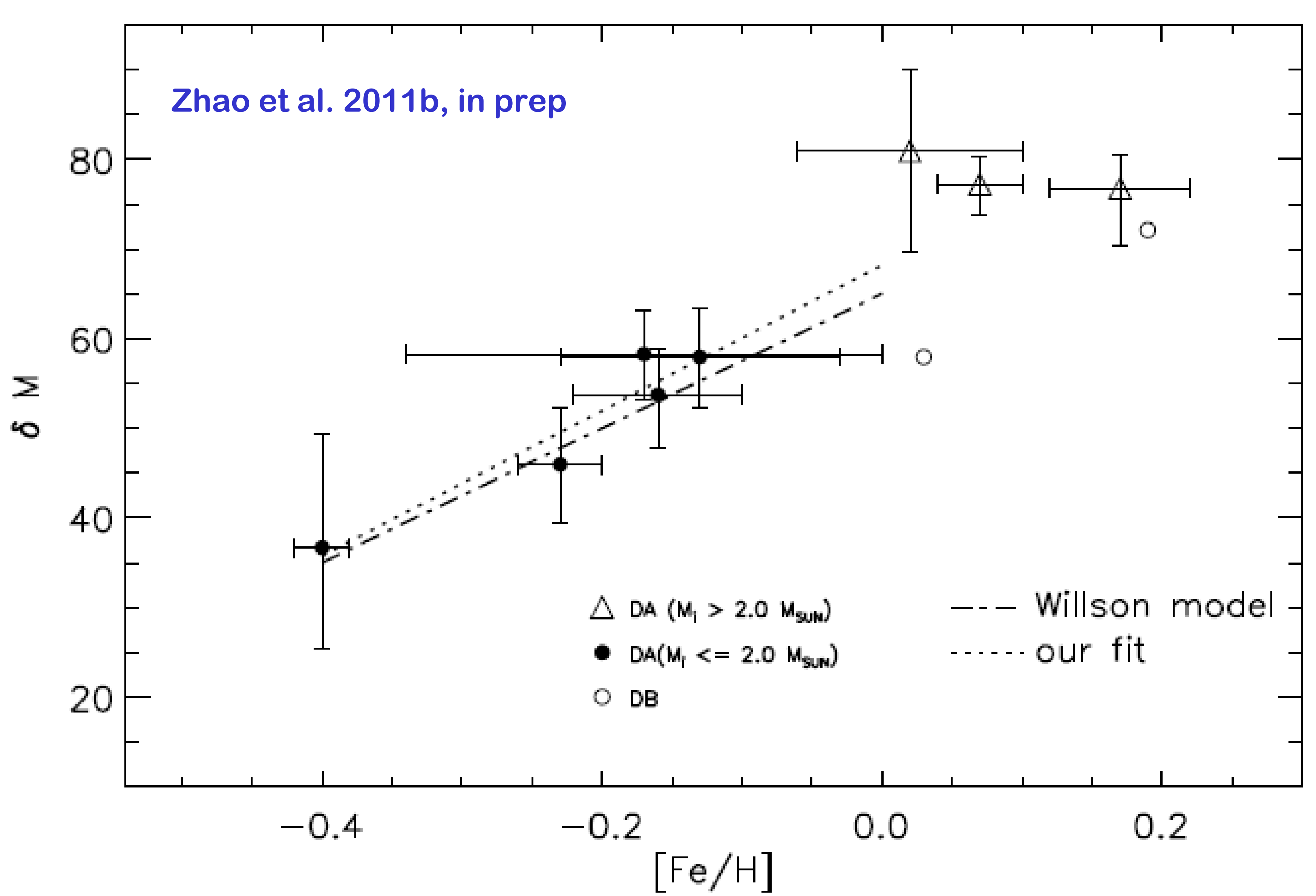


Solar metallicity stars (blue) lose more mass than lower metallicity stars (red) because:

(1) dM/dt reaches a critical value at lower luminosity, hence smaller core and more envelope to lose

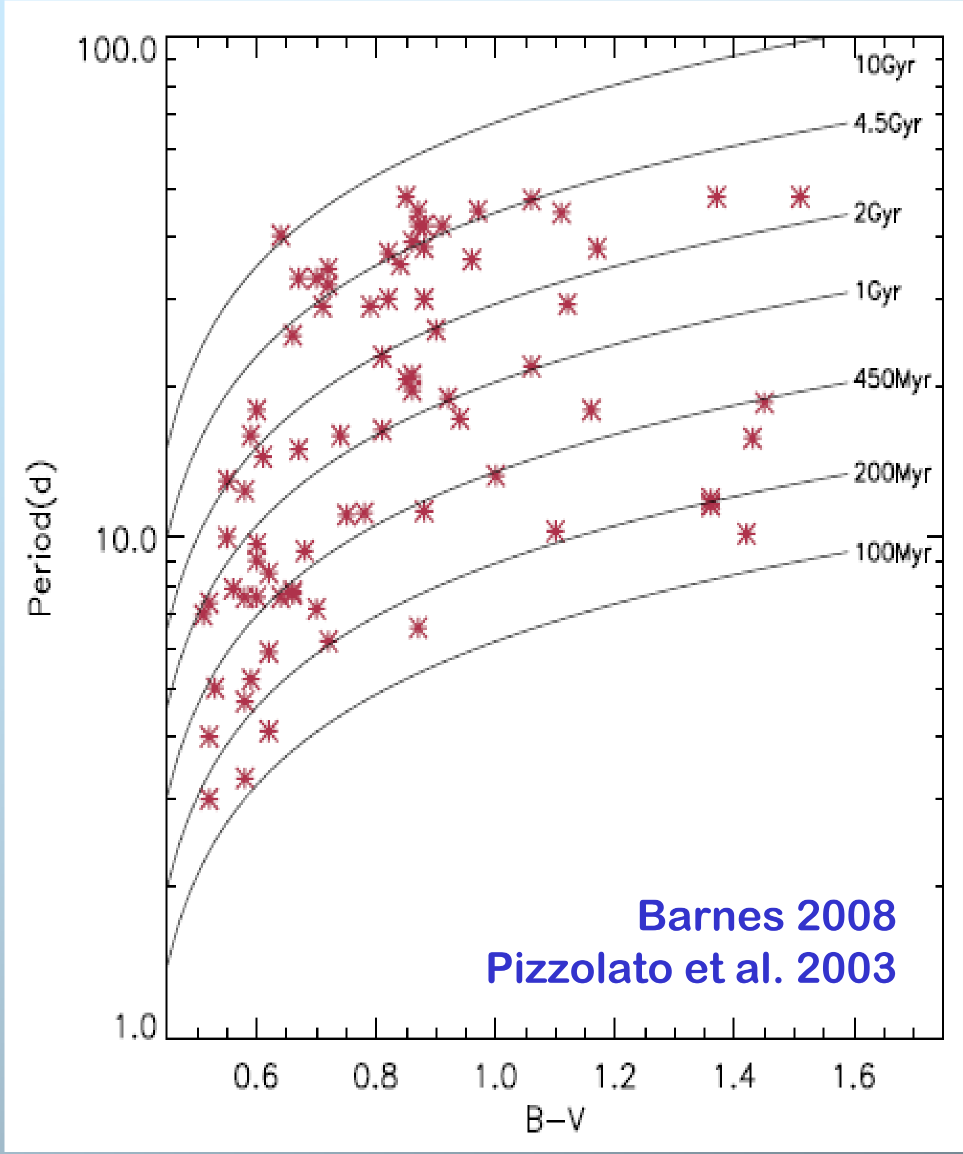
(2) More dust, higher opacity, stronger wind

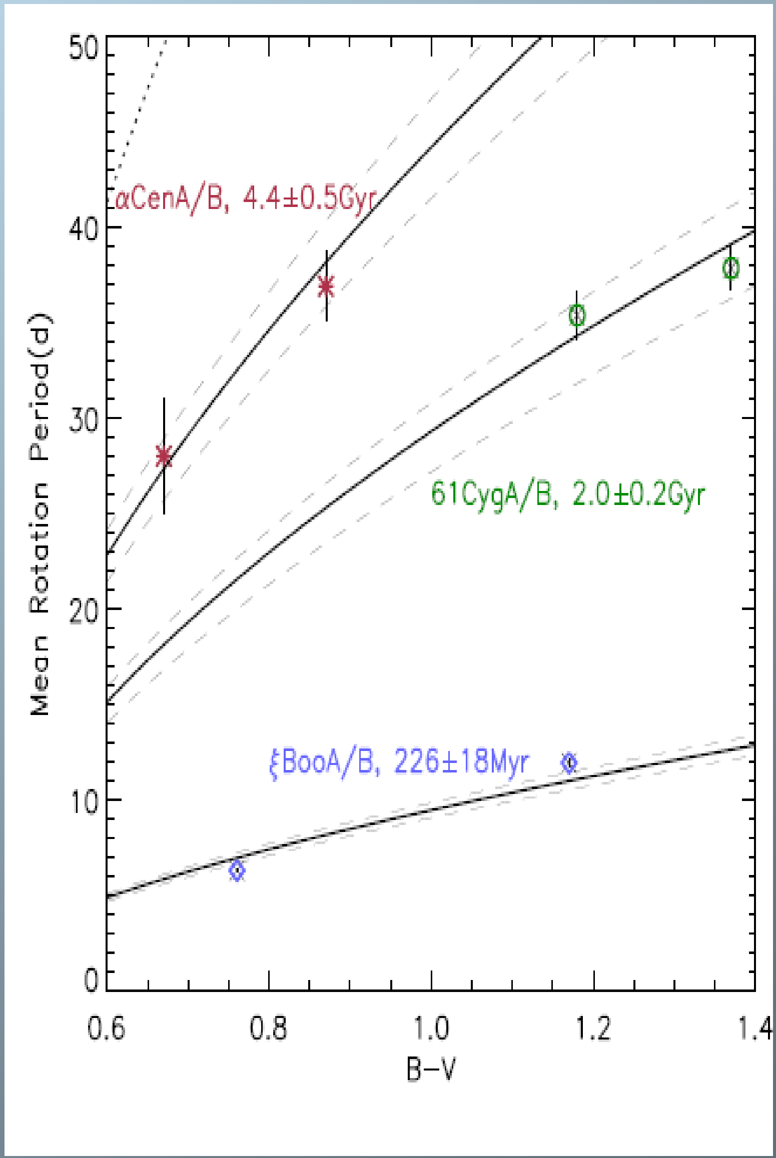
Metallicity and the IFMR



Gyrochronology

(Bird, Watson summer 2011 REU; Guinan et al. 2011)





Ongoing Work…

CA vs. age relation in WD+MS binaries

Determination of Rotation Ages

Orbit evolution and mass loss

Improving the WDLF & IFMR, e.g. [Fe/H]

Search for fragile binaries in halo

Variability in coolest WDs

High precision μ, π, V_r ⇨ m_1 & m_2

Support from U.S. National Science Foundation grant AST-0807919 and NSF (China) grants 11078019 and 10821061 is gratefully acknowledged


Thank-you!
“I don’t pretend to understand the Universe—it’s a great deal bigger than I am.”
–Thomas Carlyle 1868