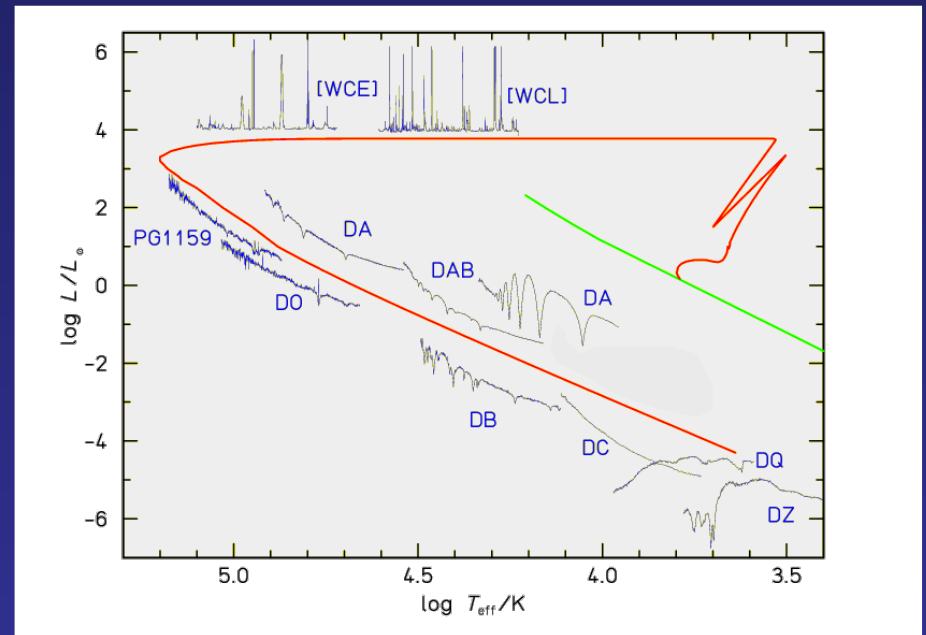


White Dwarf Stars in the Sloan Digital Sky Survey: Exploring the Tail of the Distributions

Pierre Bergeron
Université de Montréal



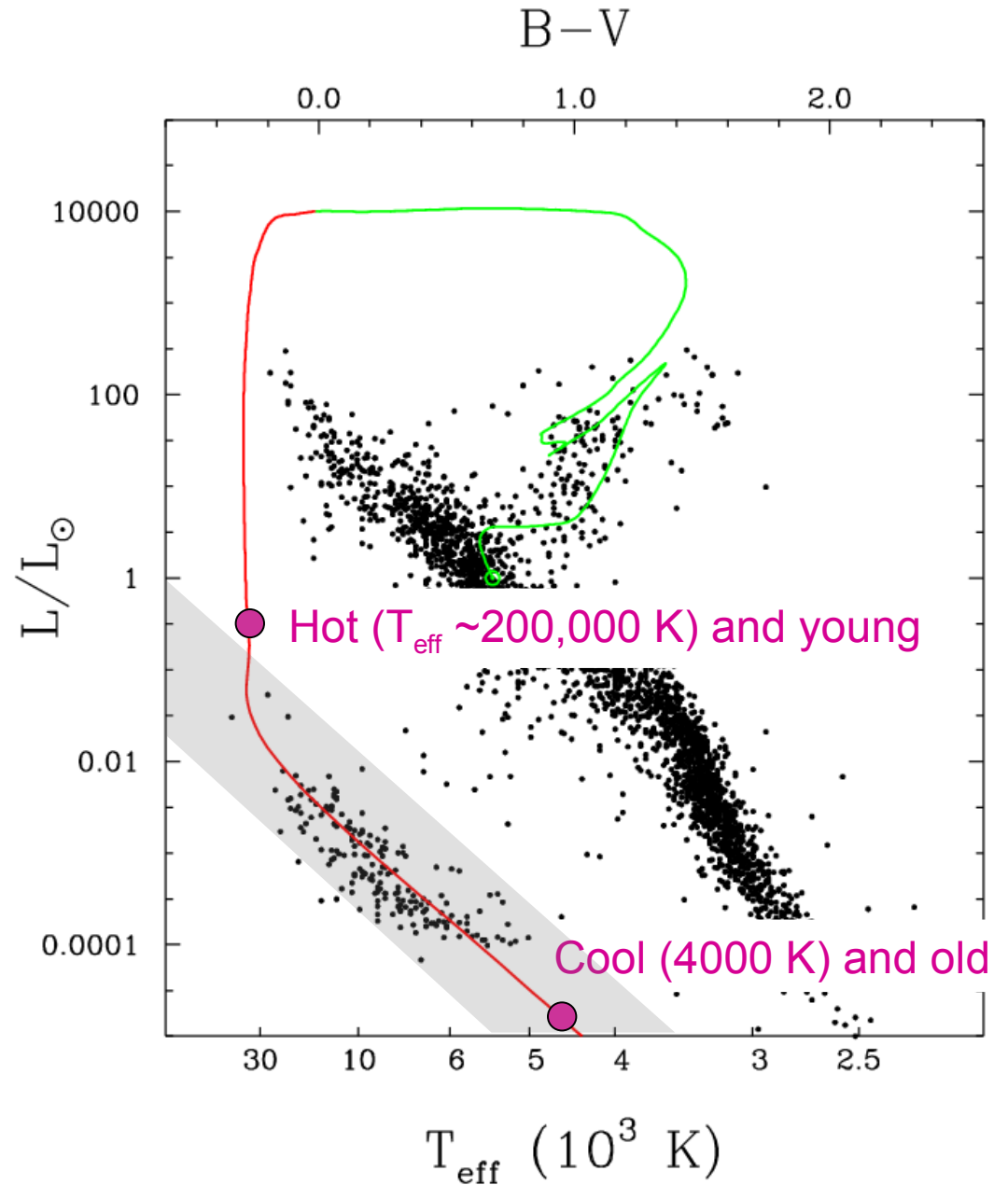
Some WD properties :

Endpoint of stellar evolution
for ~ 95 % of all stars

$M \sim 0.6 M_{\odot}$

$R \sim 0.01 R_{\odot}$

$\log_{10} \frac{\rho}{\rho_{\odot}} \sim 8$ ($\odot = 4.4$)



A CATALOG OF SPECTROSCOPICALLY IDENTIFIED WHITE DWARFS

GEORGE P. MCCOOK AND EDWARD M. SION

Department of Astronomy and Astrophysics, Villanova University

Received 1996 July 15; accepted 1998 September 21

ABSTRACT

A catalog of 2249 white dwarfs which have been identified spectroscopically is presented complete through 1996 April. This compilation is the fourth edition of the *Villanova Catalog of Spectroscopically Identified White Dwarfs*. For each degenerate star, the following data entries with references are provided: (1) a catalog coordinate designation or WD number, in order of right ascension; (2) the right ascension and declination for epoch 1950.0; (3) the spectral type based upon the new system; (4) a catalog symbol denoting binary membership; (5) a list of most names known to exist for a given star; (6) proper motion and position angle; (7) broadband *UBV* photometry, V , $B-V$, $U-B$; (8) multichannel spectrophotometry, $v(\text{MC})$, $g-r$; (9) Strömngren narrowband photometry, y , $b-y$, $u-b$; (10) an absolute visual magnitude based upon the best available color-magnitude calibration or trigonometric parallax; (11) the observed radial velocity uncorrected for gravitational redshift or solar motion; and (12) the trigonometric parallax with mean error when available. Notes for unusual or peculiar stars and a coded Reference Key alphabetized by the first author's last name are presented, as well as an expanded table cross-referencing all names to the catalog WD number. An introduction and full descriptions of the entries are provided in the text.

Subject headings: catalogs — white dwarfs

A brief history of SDSS WDs

| | <u>#WDs</u> |
|-------------------------------|-------------|
| • EDR: Harris et al. 2003 | 269 |
| • DR1: Kleinman et al. 2004 | 2551 |
| • DR3: Harris et al. 2006 | 6000 |
| • DR4: Eisenstein et al. 2006 | 9316 |
| • DR6: Kleinman et al. | 13000 (+) |



McCook & Sion (1999) : 2249 WDs i SDSS (2008) : 15300 WDs

AN INITIAL SURVEY OF WHITE DWARFS IN THE SLOAN DIGITAL SKY SURVEY

HUGH C. HARRIS,¹ JAMES LIEBERT,² S. J. KLEINMAN,³ ATSUKO NITTA,³ SCOTT F. ANDERSON,⁴ GILLIAN R. KNAPP,⁵
JUREK KRZESIŃSKI,^{3,6} GARY SCHMIDT,² MICHAEL A. STRAUSS,⁵ DAN VANDEN BERK,⁷ DANIEL EISENSTEIN,²
SUZANNE HAWLEY,⁴ BRUCE MARGON,⁸ JEFFREY A. MUNN,¹ NICOLE M. SILVESTRI,⁴ J. ALLYN SMITH,⁹
PAULA SZKODY,⁴ MATTHEW J. COLLINGE,⁵ CONARD C. DAHN,¹ XIAOHUI FAN,² PATRICK B. HALL,^{5,10}
DONALD P. SCHNEIDER,¹¹ J. BRINKMANN,³ SCOTT BURLES,¹² JAMES E. GUNN,⁵ GREGORY S. HENNESSY,¹³
ROBERT HINDSLEY,¹⁴ ZELJKO IVEZIĆ,⁵ STEPHEN KENT,^{15,16} DONALD Q. LAMB,¹⁶ ROBERT H. LUPTON,⁵
R. C. NICHOL,¹⁷ JEFFREY R. PIER,¹ DAVID J. SCHLEGEL,⁵ MARK SUBBARAO,¹⁶ ALAN UOMOTO,¹⁸
BRIAN YANNY,¹⁵ AND DONALD G. YORK¹⁶

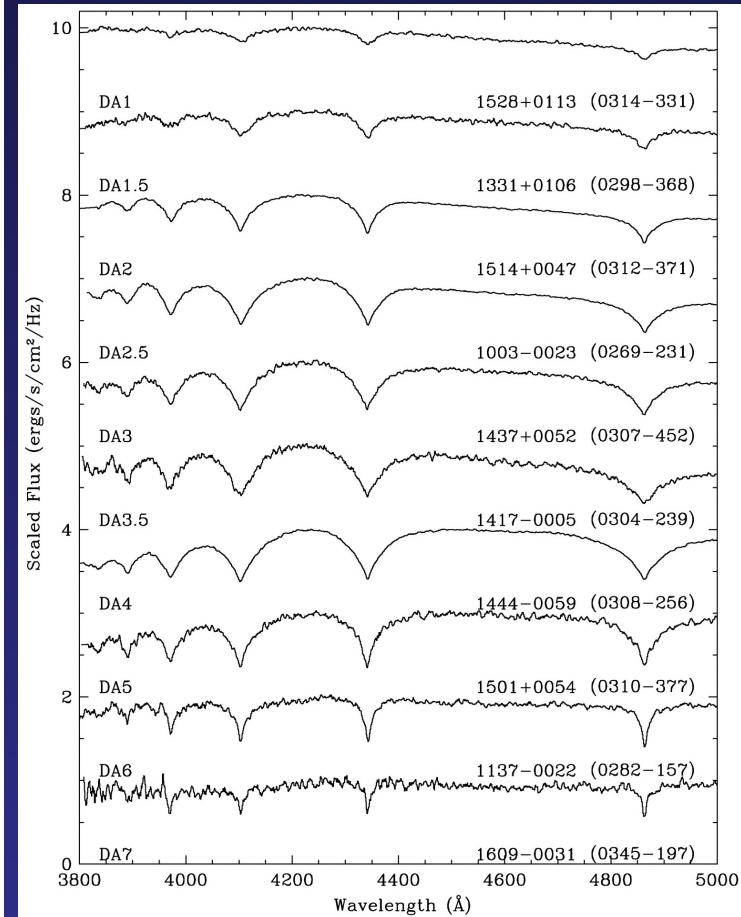
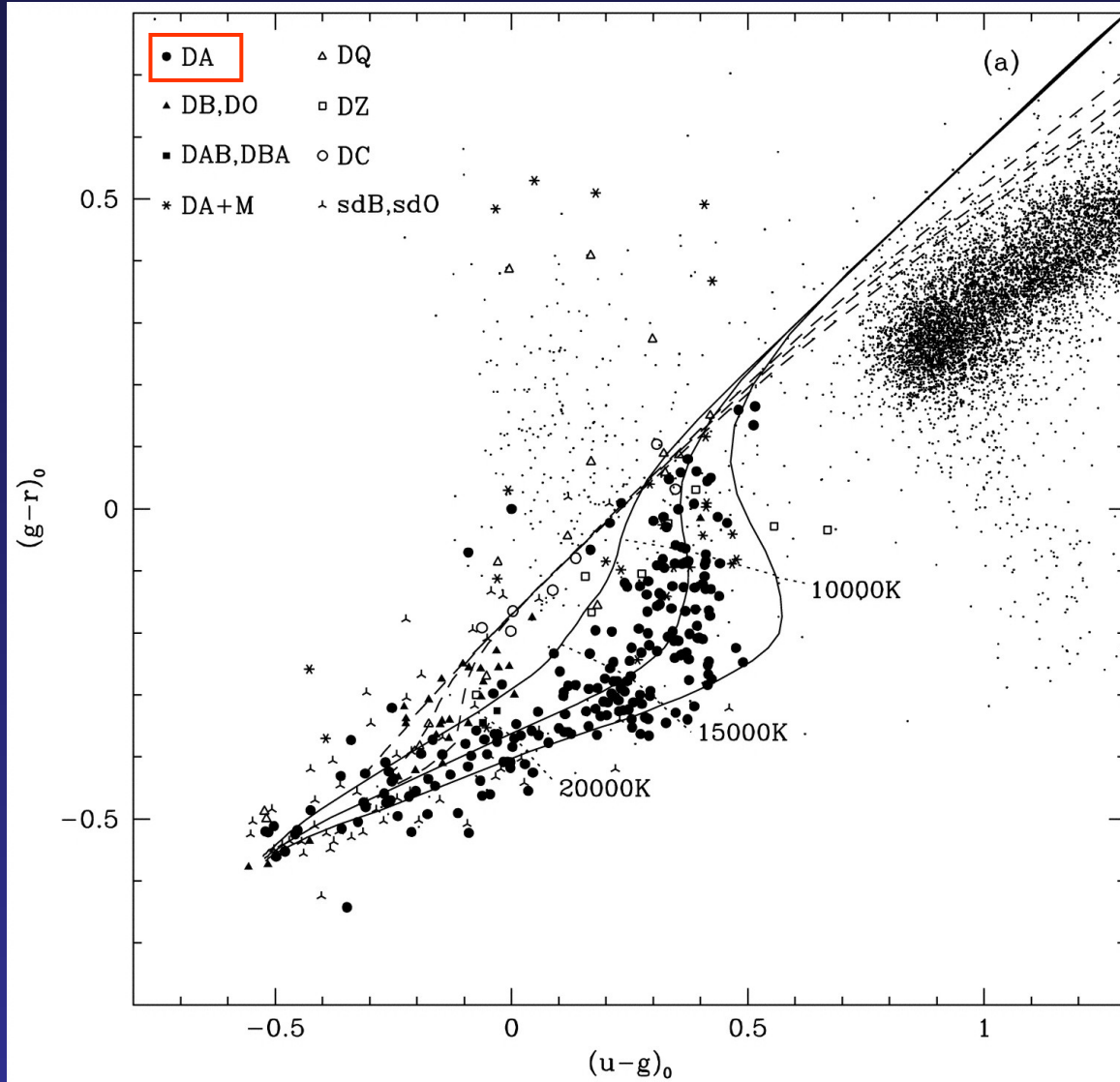
Received 2003 March 11; accepted 2003 May 12

ABSTRACT

An initial assessment is made of white dwarf and hot subdwarf stars observed in the Sloan Digital Sky Survey. In a small area of sky (190 square degrees), observed much like the full survey will be, 269 white dwarfs (WDs) and 56 hot subdwarfs are identified spectroscopically where only 44 white dwarfs and five hot subdwarfs were known previously. Most are ordinary DA (hydrogen atmosphere) and DB (helium) types. In addition, in the full survey to date, a number of WDs have been found with uncommon spectral types. Among these are blue DQ stars displaying lines of atomic carbon; red DQ stars showing molecular bands of C₂ with a wide variety of strengths; DZ stars where Ca and occasionally Mg, Na, and/or Fe lines are detected; and magnetic WDs with a wide range of magnetic field strengths in DA, DB, DQ, and (probably) DZ spectral types. Photometry alone allows identification of stars hotter than 12,000 K, and the density of these stars for $15 < g < 20$ is found to be $\sim 2.2 \text{ deg}^{-2}$ at Galactic latitudes of 29° – 62° . Spectra are obtained for roughly half of these hot stars. The spectra show that for $15 < g < 17$, 40% of hot stars are WDs, and the fraction of WDs rises to $\sim 90\%$ at $g = 20$. The remainder are hot sdB and sdO stars.

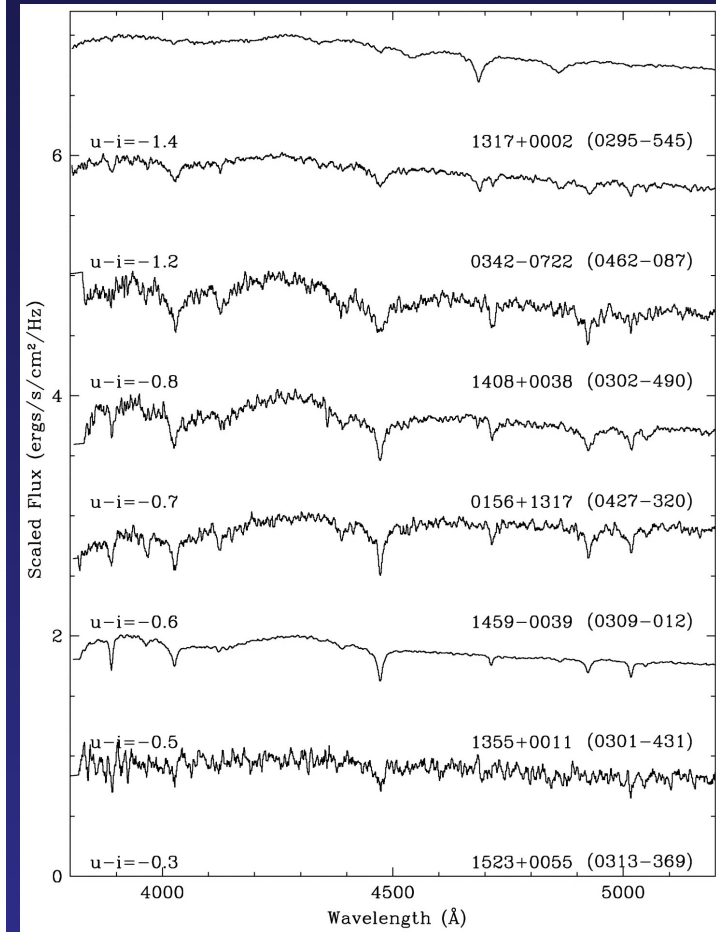
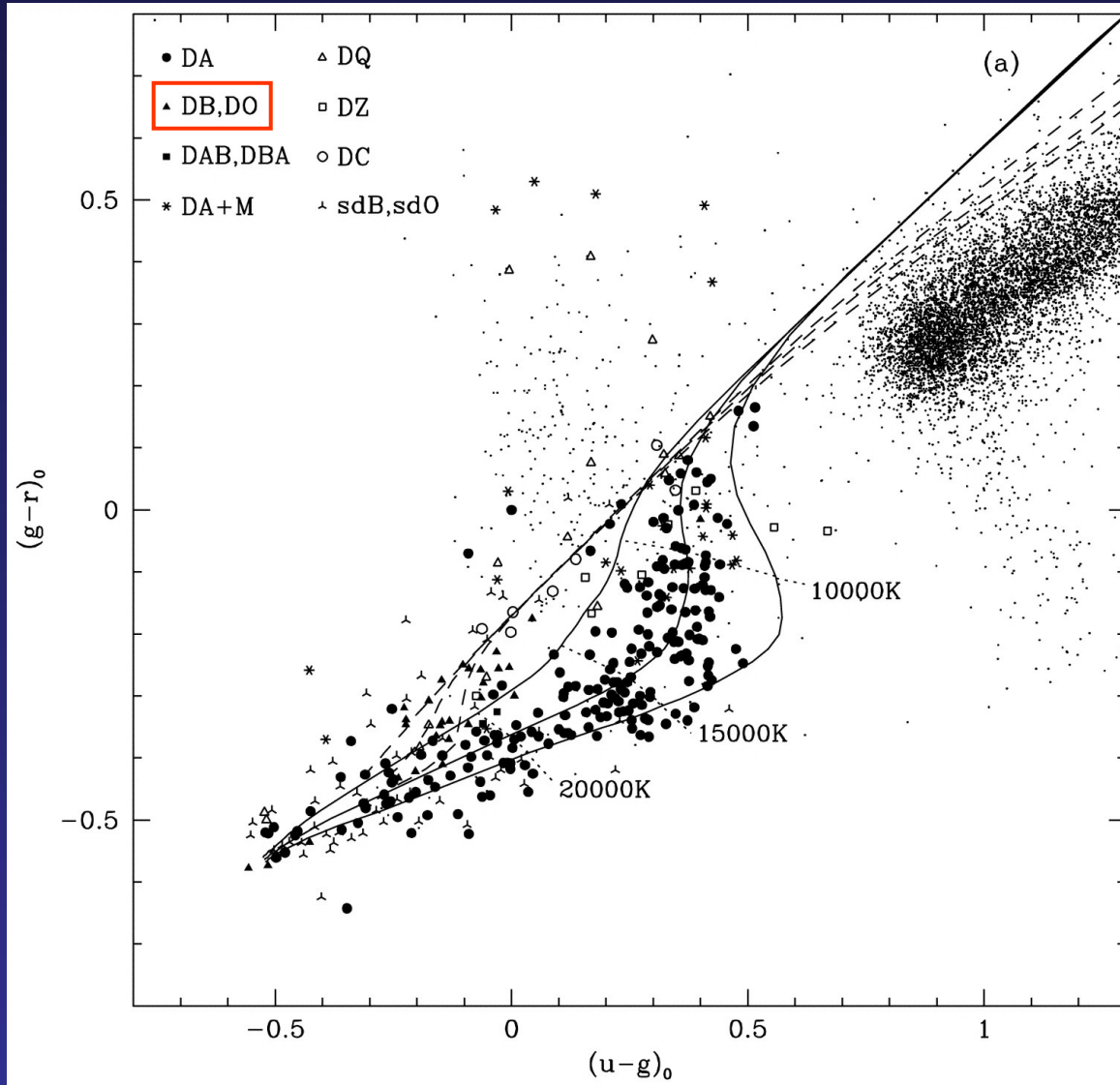
Key words: stars: chemically peculiar — stars: magnetic fields — surveys — white dwarfs

SDSS Early Data Release



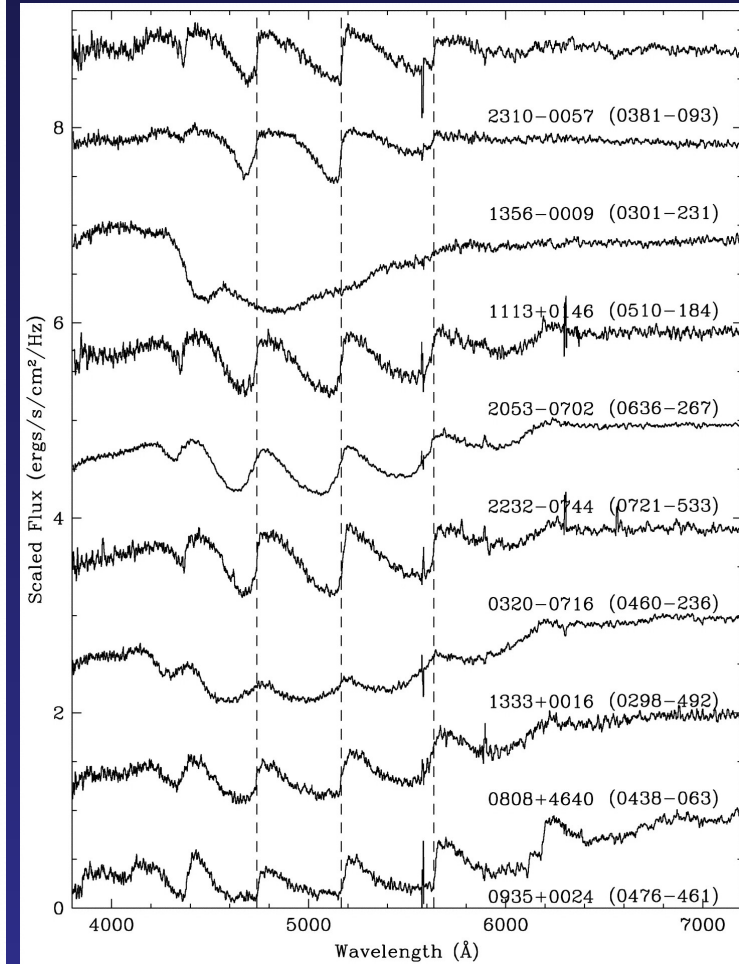
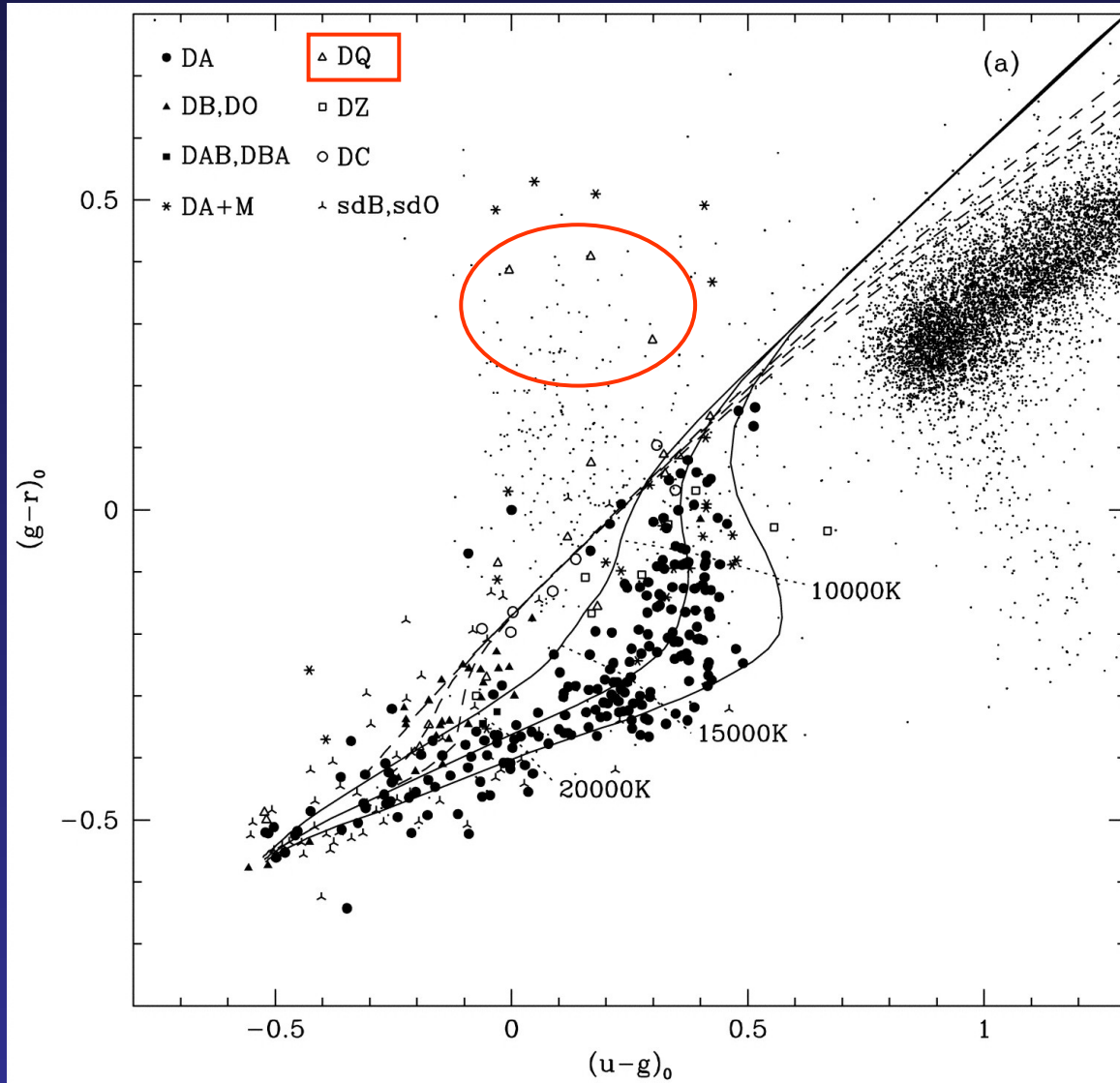
Spectra dominated
by H Balmer lines

SDSS Early Data Release



Spectra dominated by He I (DB)
and He II (DO) lines

SDSS Early Data Release



Spectra dominated by C I lines or C₂ Swan bands

A CATALOG OF SPECTROSCOPICALLY CONFIRMED WHITE DWARFS FROM THE SLOAN DIGITAL SKY SURVEY DATA RELEASE 4

DANIEL J. EISENSTEIN,^{1,2} JAMES LIEBERT,¹ HUGH C. HARRIS,³ S. J. KLEINMAN,^{4,5} ATSUKO NITTA,^{4,5} NICOLE SILVESTRI,⁶
SCOTT A. ANDERSON,⁶ J. C. BARENTINE,⁴ HOWARD J. BREWINGTON,⁴ J. BRINKMANN,⁴ MICHAEL HARVANEK,⁴
JUREK KRZESIŃSKI,^{4,7} ERIC H. NEILSEN, JR.,⁸ DAN LONG,⁴ DONALD P. SCHNEIDER,⁹ AND STEPHANIE A. SNEDDEN⁴

Received 2005 December 19; accepted 2006 June 13

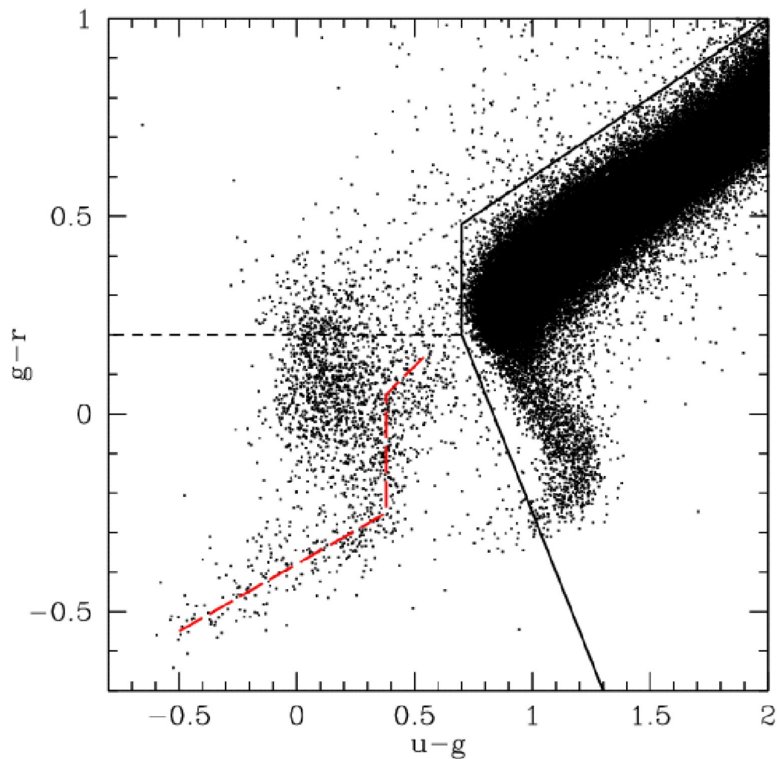
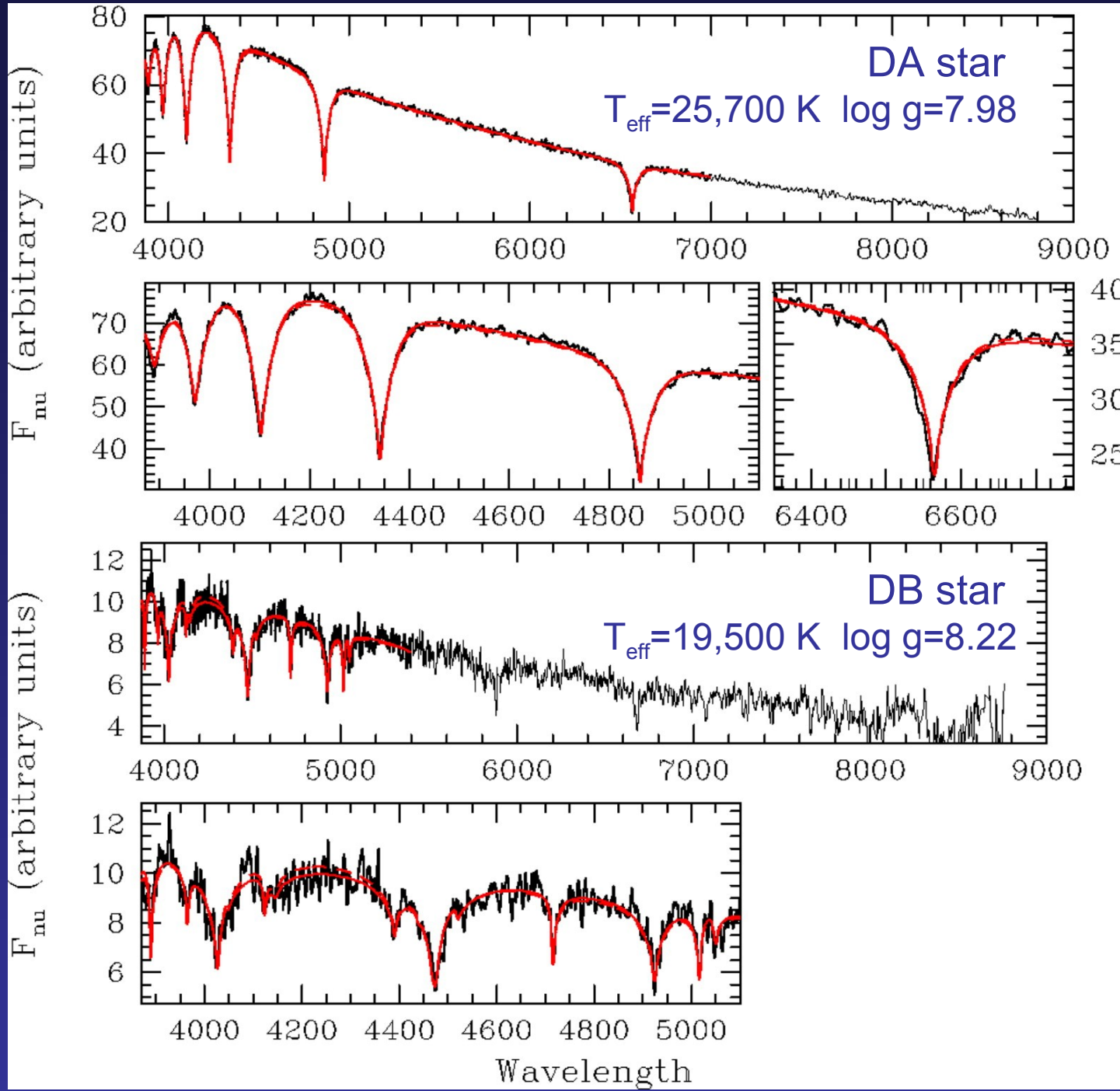


TABLE 2
WHITE DWARF DOMINANT CLASSIFICATIONS

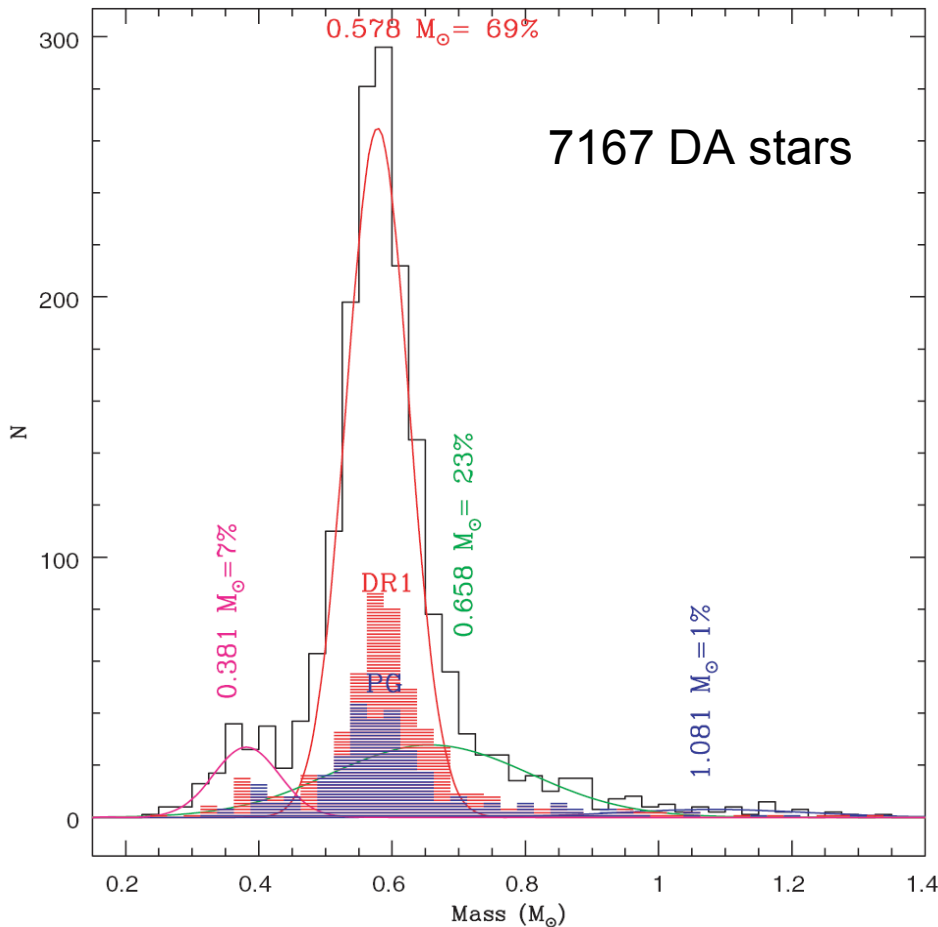
| Classification ^a | Number |
|-----------------------------|--------|
| DA..... | 8000 |
| DB..... | 713 |
| DC..... | 289 |
| DH..... | 9 |
| DO..... | 31 |
| DQ..... | 104 |
| DZ..... | 133 |
| PG1159..... | 10 |
| WD..... | 27 |



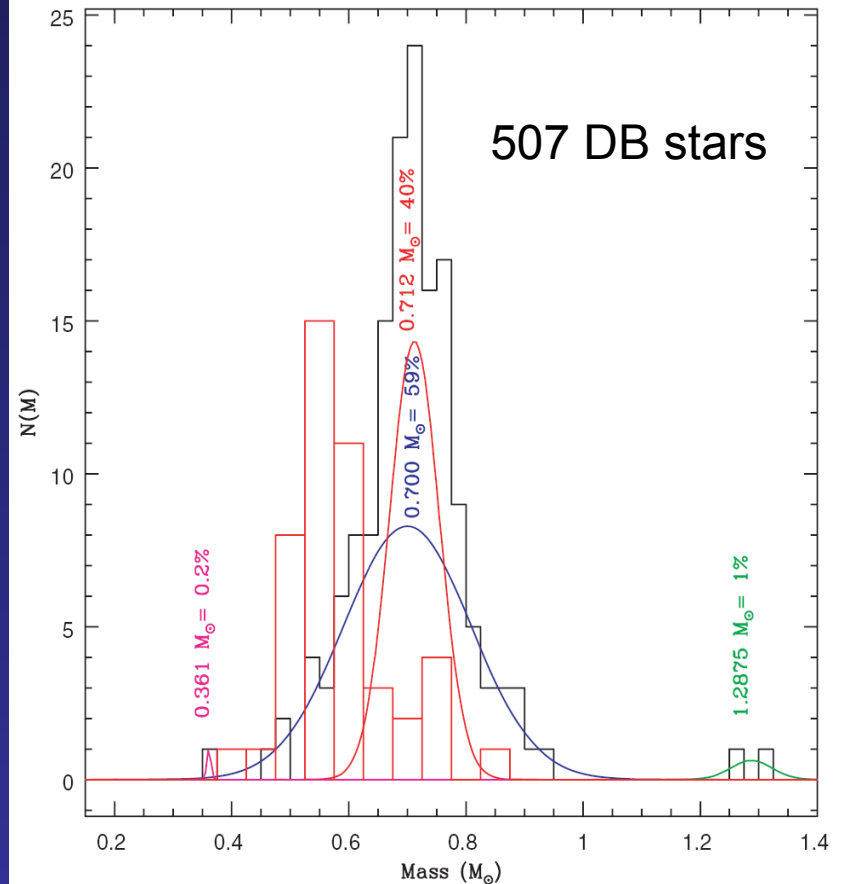
White dwarf mass distribution in the SDSS

S. O. Kepler,^{1*} S. J. Kleinman,² A. Nitta,³ D. Koester,⁴ B. G. Castanheira,¹
 O. Giovannini,⁵ A. F. M. Costa¹ and L. Althaus⁶

Sloan DR4 DAs $g < 19$ $T_{\text{eff}} > 12000\text{K}$ $\langle M \rangle = 0.593 \pm 0.016 M_{\odot}$



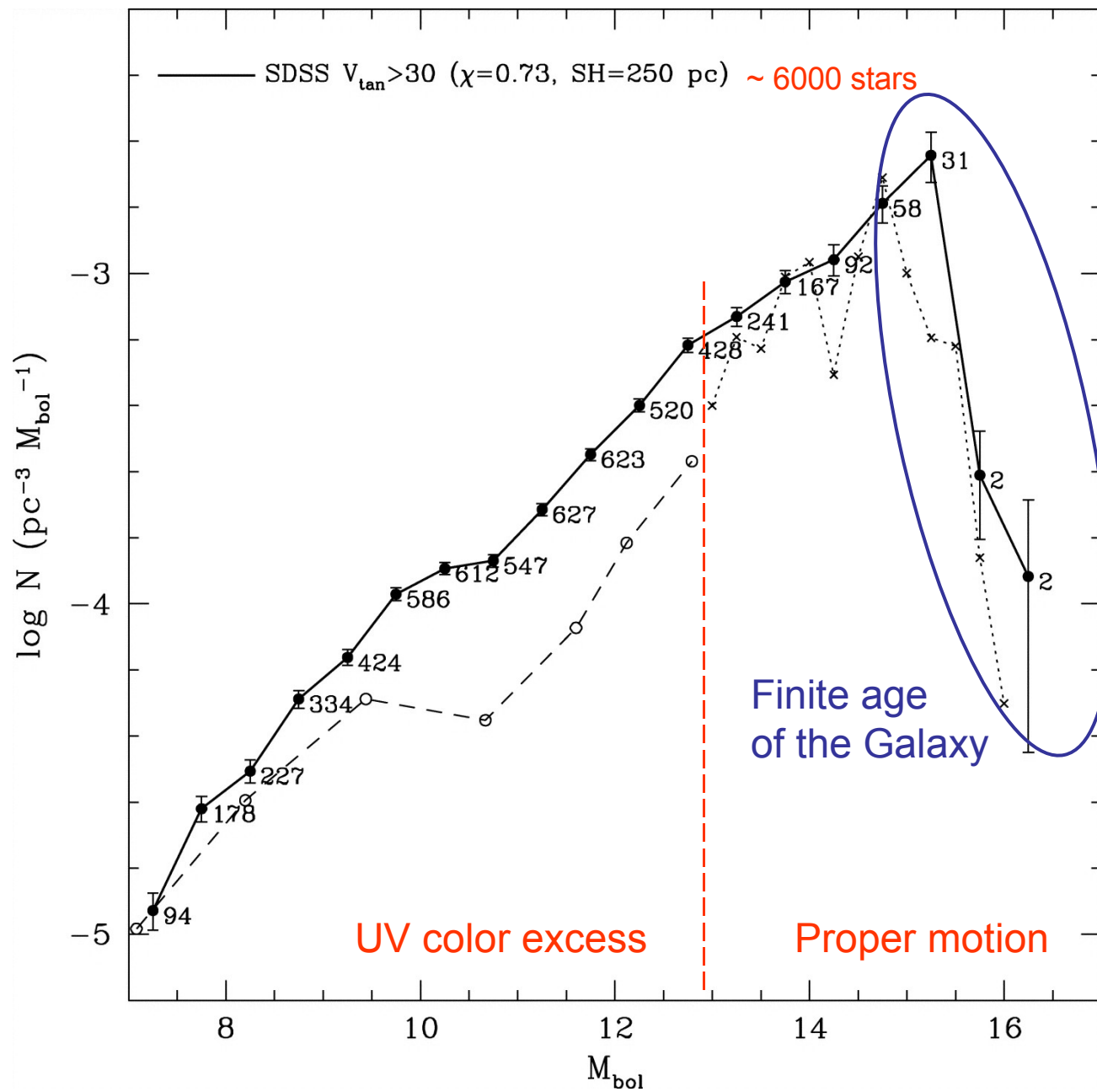
Sloan DR4 DB Mass Distribution $g < 19$ $T_{\text{eff}} > 16000\text{K}$ $\langle M \rangle = 0.711 \pm 0.009$



THE WHITE DWARF LUMINOSITY FUNCTION FROM SLOAN DIGITAL SKY SURVEY IMAGING DATA

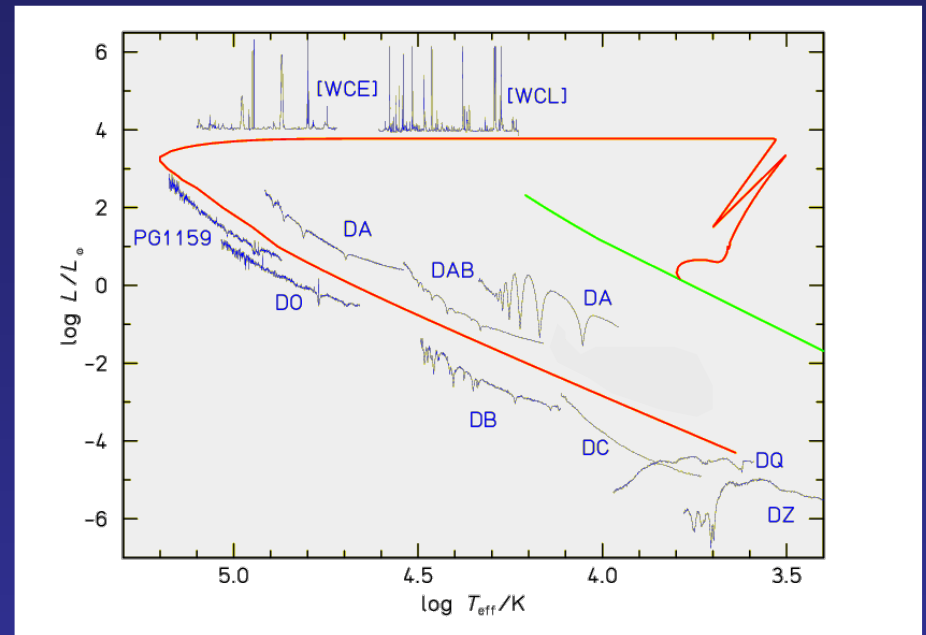
HUGH C. HARRIS,¹ JEFFREY A. MUNN,¹ MUKREMIN KILIC,² JAMES LIEBERT,³ KURTIS A. WILLIAMS,³ TED VON HIPPEL,²
STEPHEN E. LEVINE,¹ DAVID G. MONET,¹ DANIEL J. EISENSTEIN,³ S. J. KLEINMAN,⁴ T. S. METCALFE,⁵
ATSUKO NITTA,⁴ D. E. WINGET,² J. BRINKMANN,⁴ MASATAKA FUKUGITA,⁶ G. R. KNAPP,⁷
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Received 2005 March 19; accepted 2005 September 9



White Dwarf Stars in the Sloan Digital Sky Survey: Exploring the Tail of the Distributions

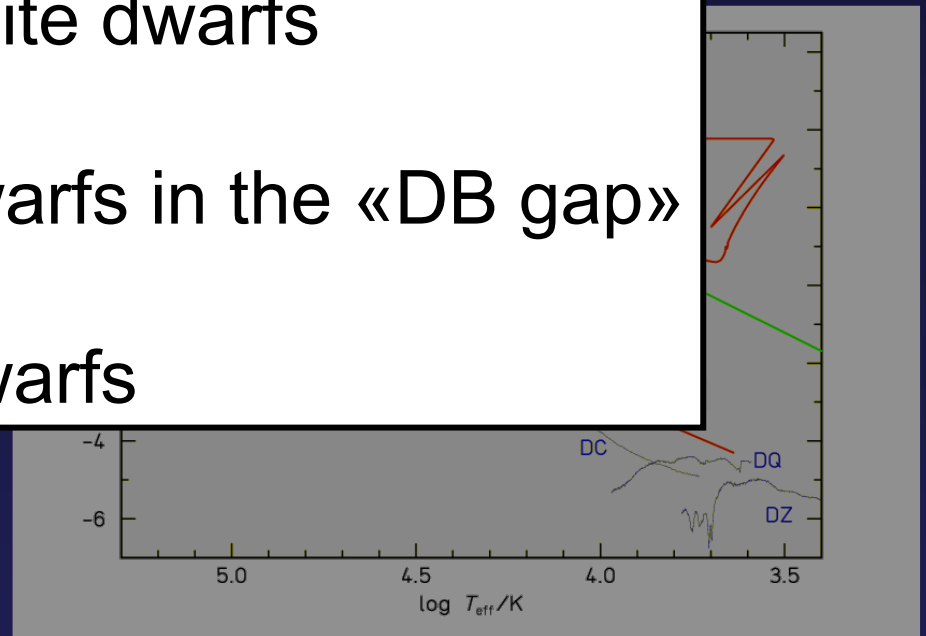
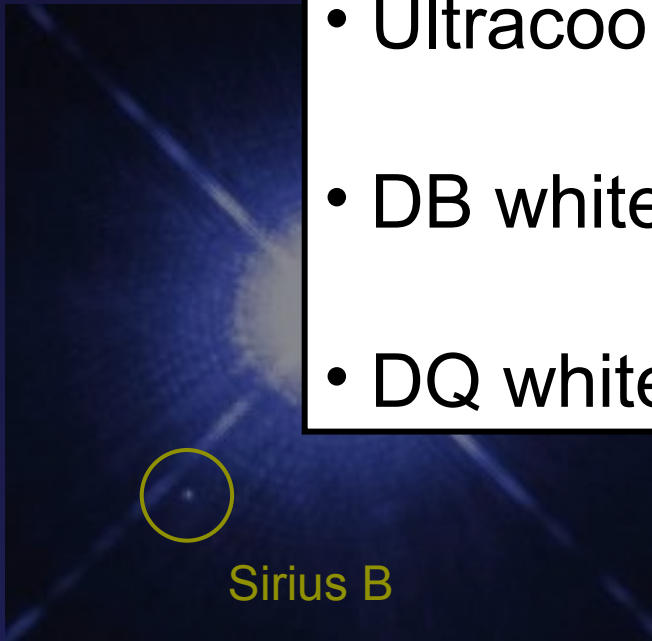
Pierre Bergeron
Université de Montréal



White Dwarf Stars in the Sloan Digital Sky Survey: Exploring the Tail of the Distributions

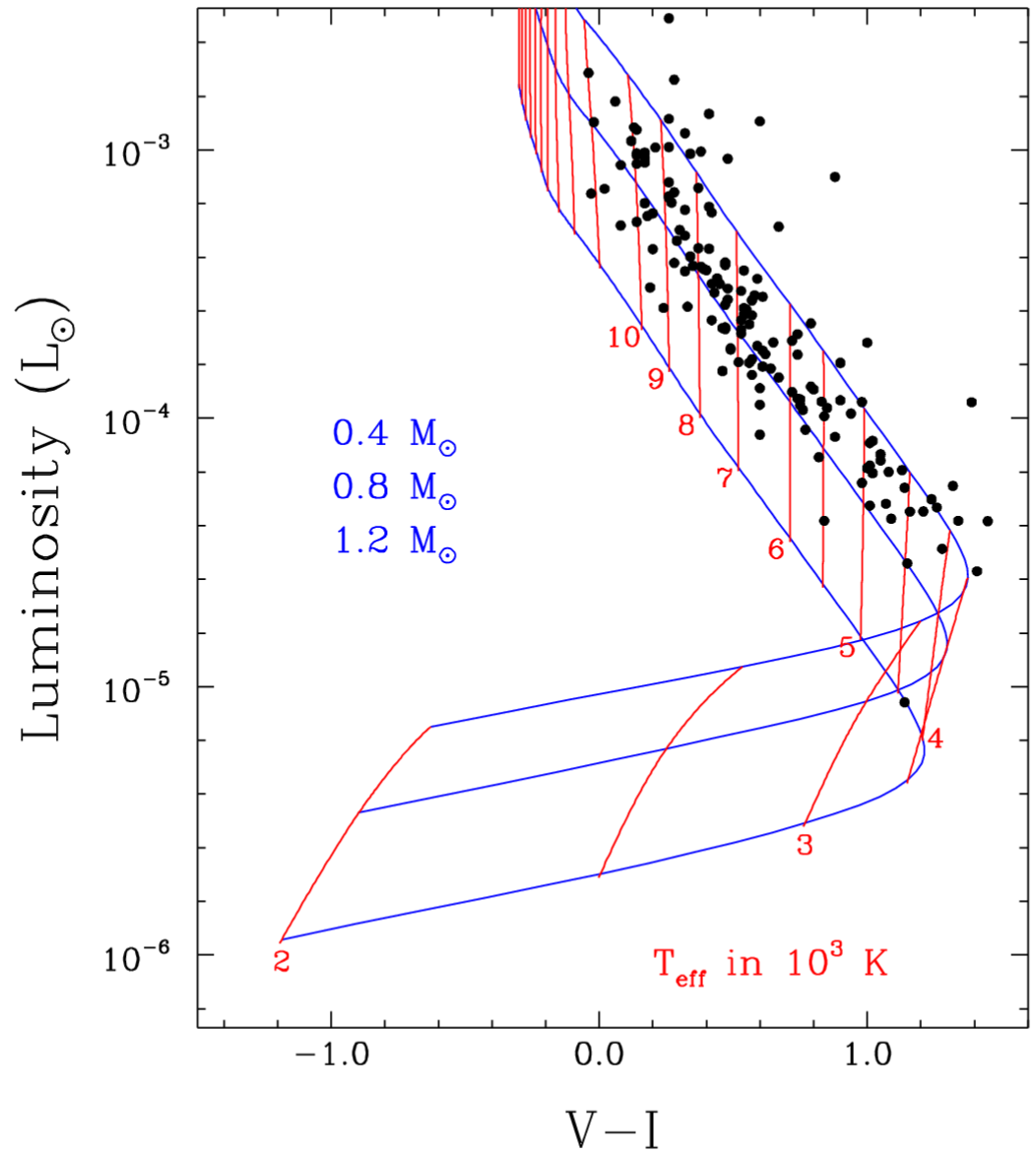
Pierre Bergeron
Université de Montréal

- Ultracool white dwarfs
- DB white dwarfs in the «DB gap»
- DQ white dwarfs



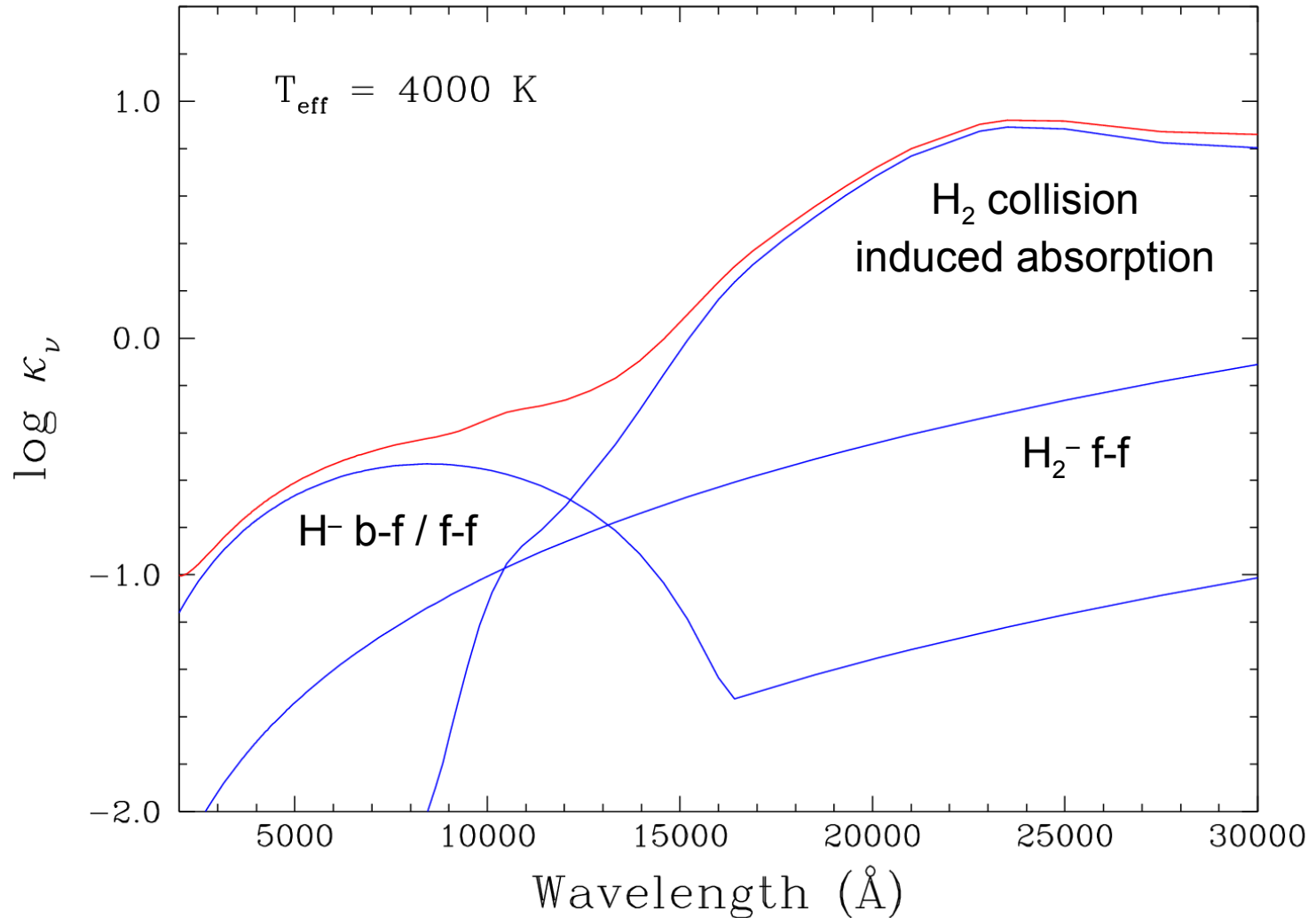
Ultracool White Dwarfs

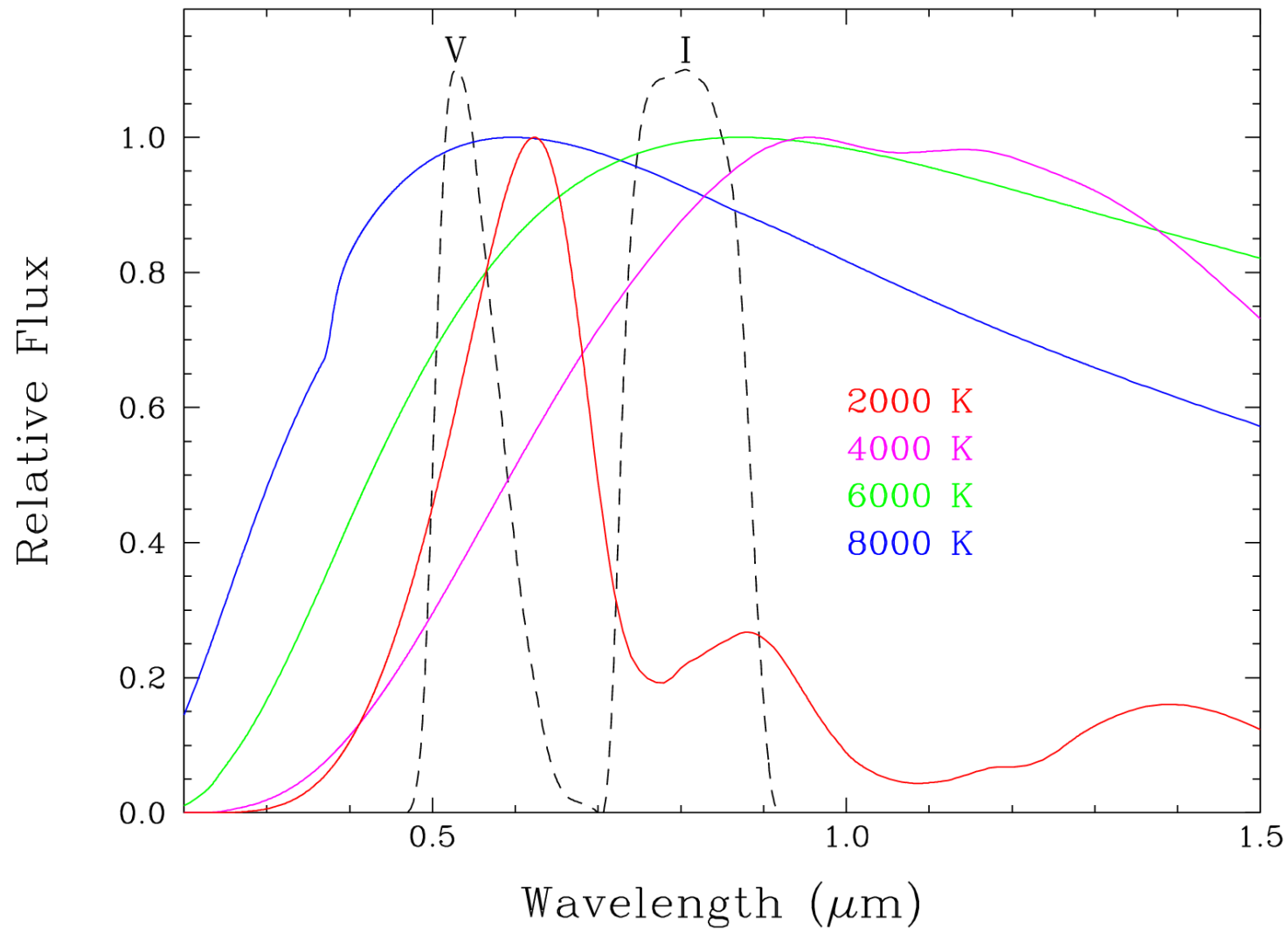


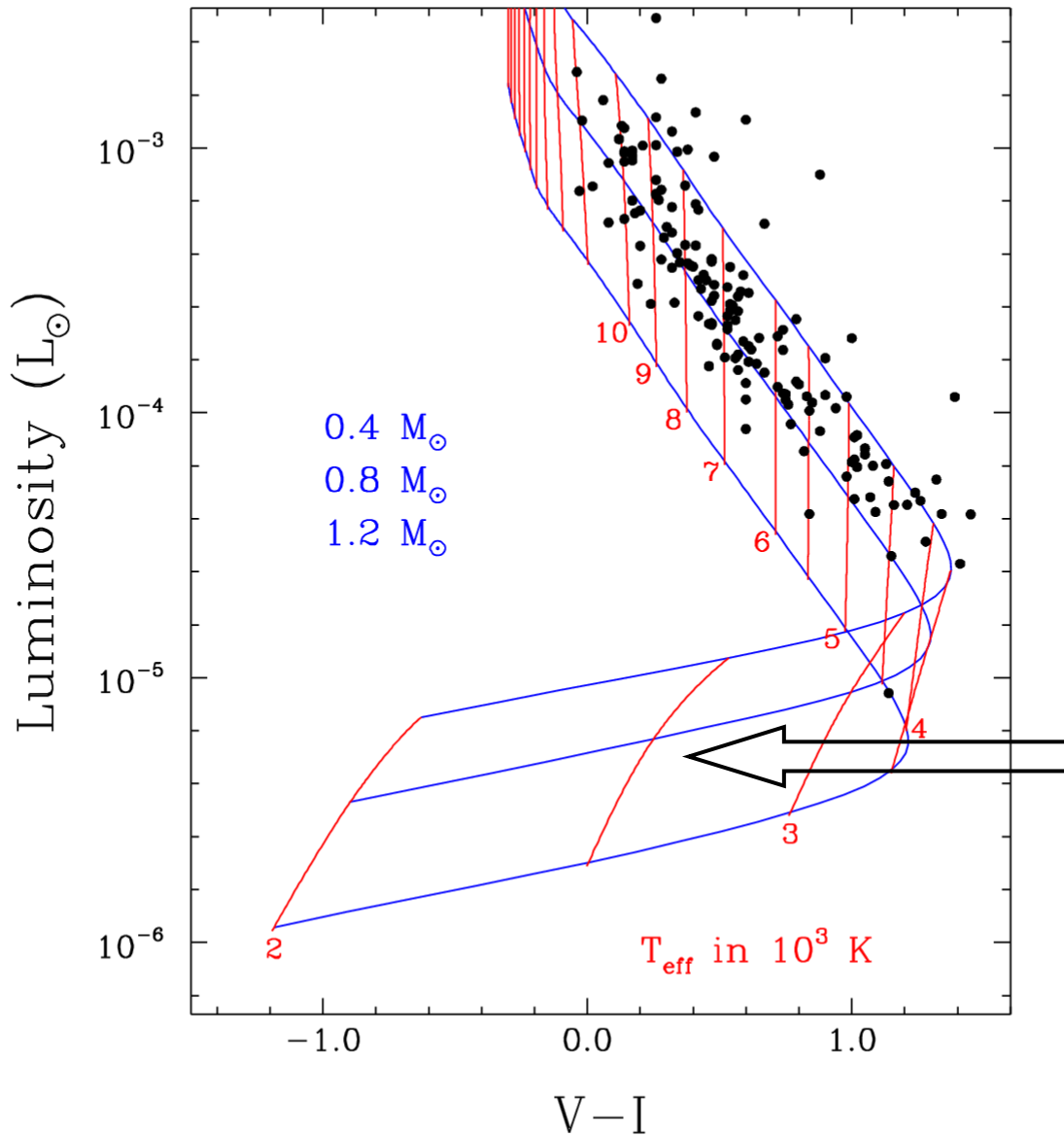


Data from Bergeron,
Leggett, & Ruiz
(2001, ApJS)

Main opacity sources at the photosphere of a cool white dwarf







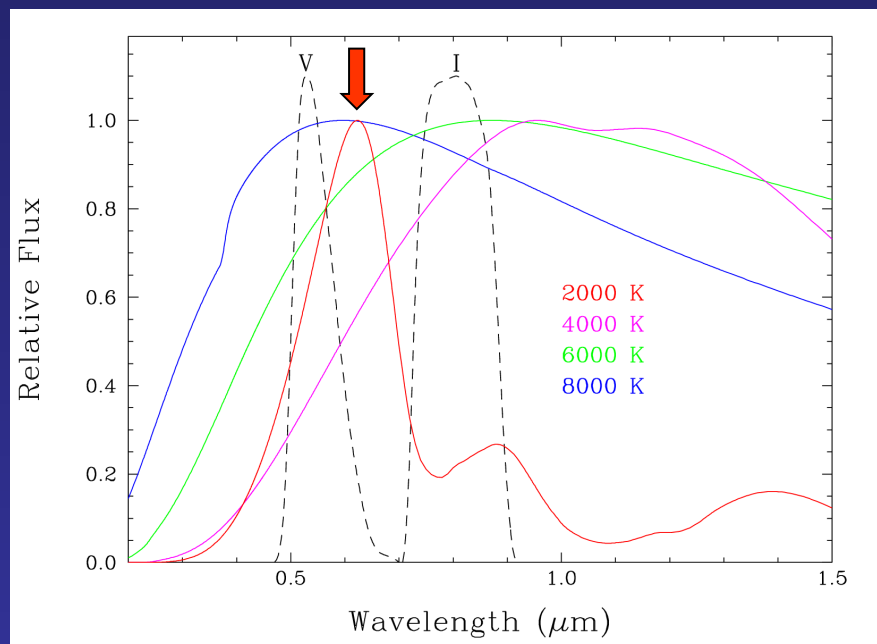
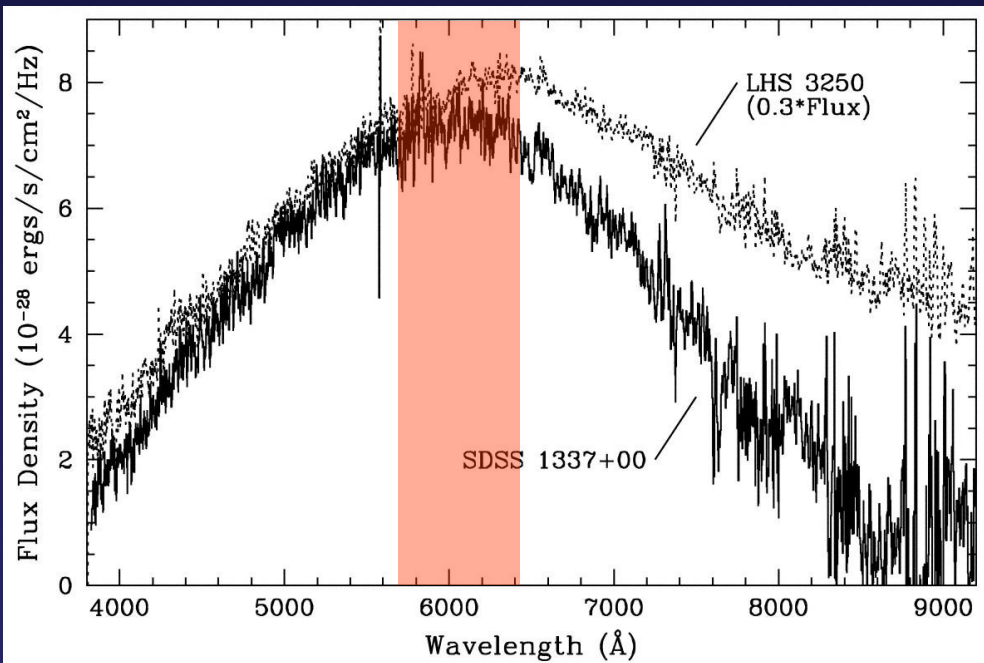
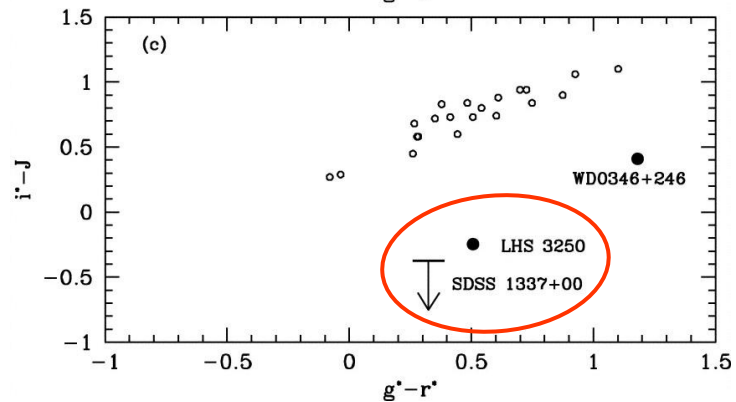
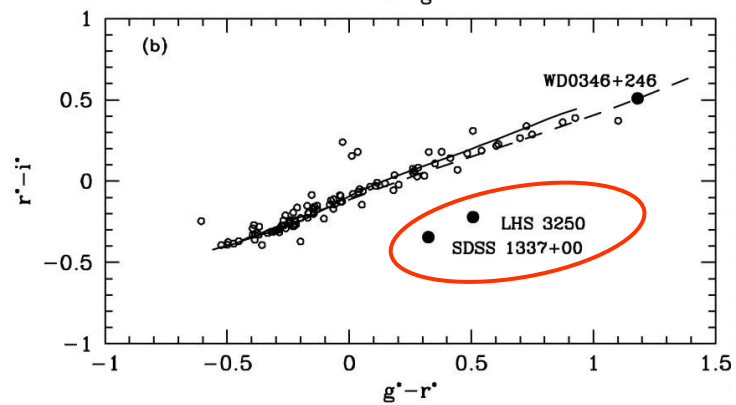
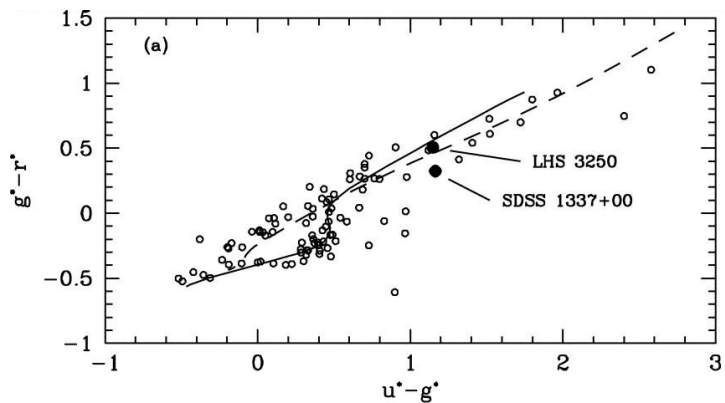
Data from Bergeron,
Leggett, & Ruiz
(2001, ApJS)

Ultracool (old) white
dwarfs become
increasingly bluer !!!

A NEW VERY COOL WHITE DWARF DISCOVERED BY THE SLOAN DIGITAL SKY SURVEY

HUGH C. HARRIS,¹ BRAD M. S. HANSEN,² JAMES LIEBERT,³ DANIEL E. VANDEN BERK,⁴ SCOTT F. ANDERSON,⁵ G. R. KNAPP,²
XIAOHUI FAN,^{2,6} BRUCE MARGON,⁵ JEFFREY A. MUNN,¹ R. C. NICHOL,⁷ JEFFREY R. PIER,¹ DONALD P. SCHNEIDER,⁸
J. ALLYN SMITH,⁹ D. E. WINGET,¹⁰ DONALD G. YORK,^{11,12} JOHN E. ANDERSON, JR.,⁴ J. BRINKMANN,¹³
SCOTT BURLES,^{4,11} BING CHEN,¹⁴ A. J. CONNOLLY,¹⁵ ISTVÁN CSABAI,^{14,16} JOSHUA A. FRIEMAN,^{4,11}
JAMES E. GUNN,² G. S. HENNESSY,¹⁷ ROBERT B. HINDSLEY,¹⁸ ŽELJKO IVEZIĆ,² STEPHEN KENT,^{4,11}
D. Q. LAMB,¹¹ ROBERT H. LUPTON,² HEIDI JO NEWBERG,¹⁹ DAVID J. SCHLEGEL,²
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ALAN UOMOTO,¹⁴ AND BRIAN YANNY⁴

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DISCOVERY OF NEW ULTRACOOOL WHITE DWARFS IN THE SLOAN DIGITAL SKY SURVEY

EVALYN GATES,¹ GEZA GYUK,^{1,2} HUGH C. HARRIS,³ MARK SUBBARAO,^{1,2} SCOTT ANDERSON,⁴ S. J. KLEINMAN,⁵
JAMES LIEBERT,⁶ HOWARD BREWINGTON,⁵ J. BRINKMANN,⁵ MICHAEL HARVANEK,⁵ JUREK KRZESINSKI,^{5,7} DON Q. LAMB,¹
DAN LONG,⁵ ERIC H. NEILSEN, JR.,⁸ PETER R. NEWMAN,⁵ ATSUKO NITTA,⁵ AND STEPHANIE A. SNEDDEN⁵

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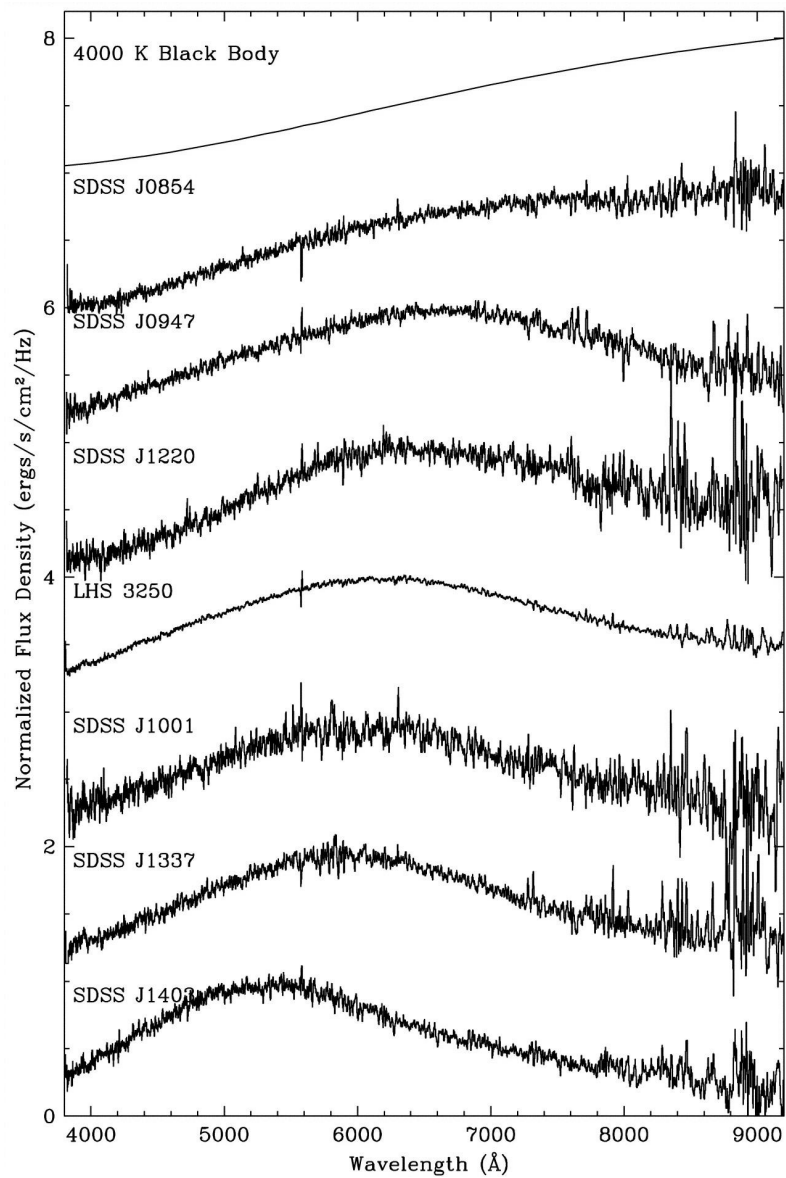
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ADDITIONAL ULTRACOOOL WHITE DWARFS FOUND IN THE SLOAN DIGITAL SKY SURVEY

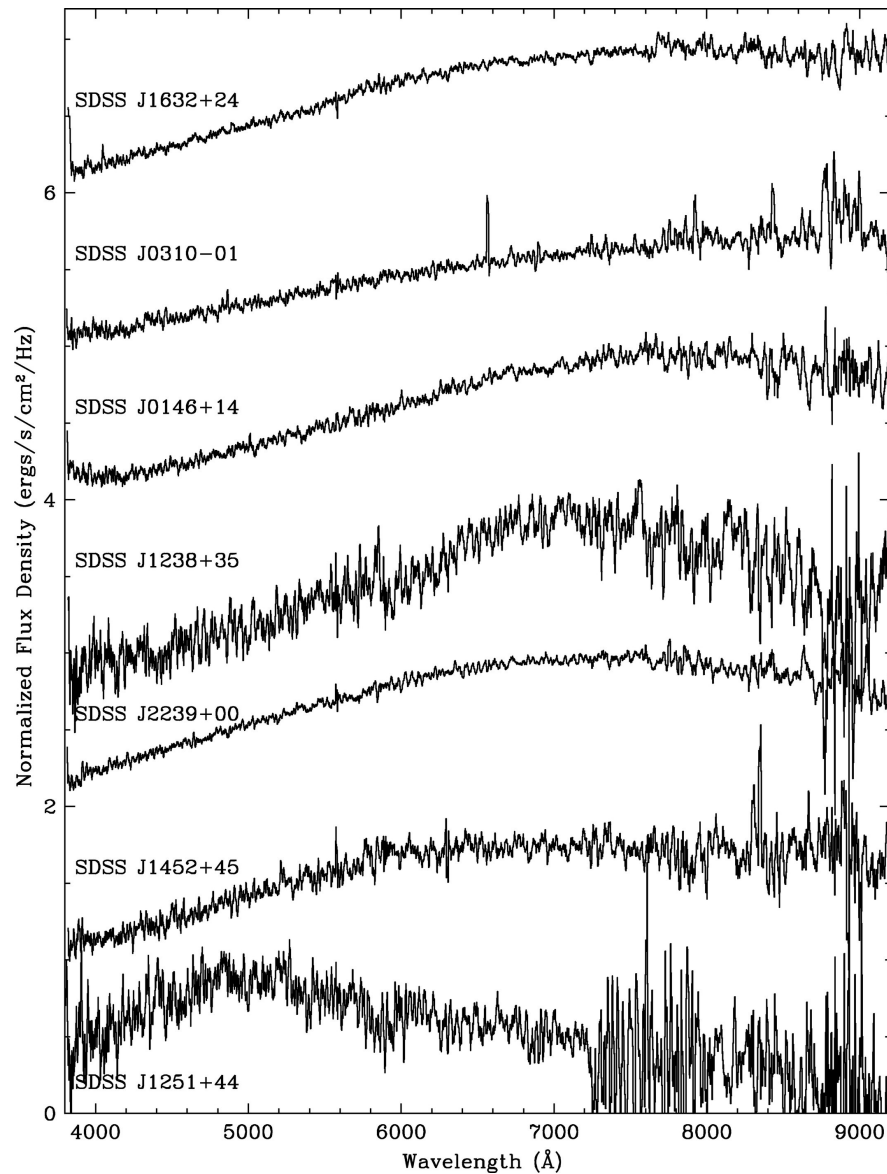
HUGH C. HARRIS,¹ EVALYN GATES,² GEZA GYUK,^{2,3} MARK SUBBARAO,^{2,3} SCOTT F. ANDERSON,⁴ PATRICK B. HALL,⁵
JEFFREY A. MUNN,¹ JAMES LIEBERT,⁶ GILLIAN R. KNAPP,⁷ D. BIZYAEV,⁸ E. MALANUSHENKO,⁸
V. MALANUSHENKO,⁸ K. PAN,⁸ DONALD P. SCHNEIDER,⁹ AND J. ALLYN SMITH¹⁰

Received 2007 September 20; accepted 2008 January 8

Gates et al. (2004)



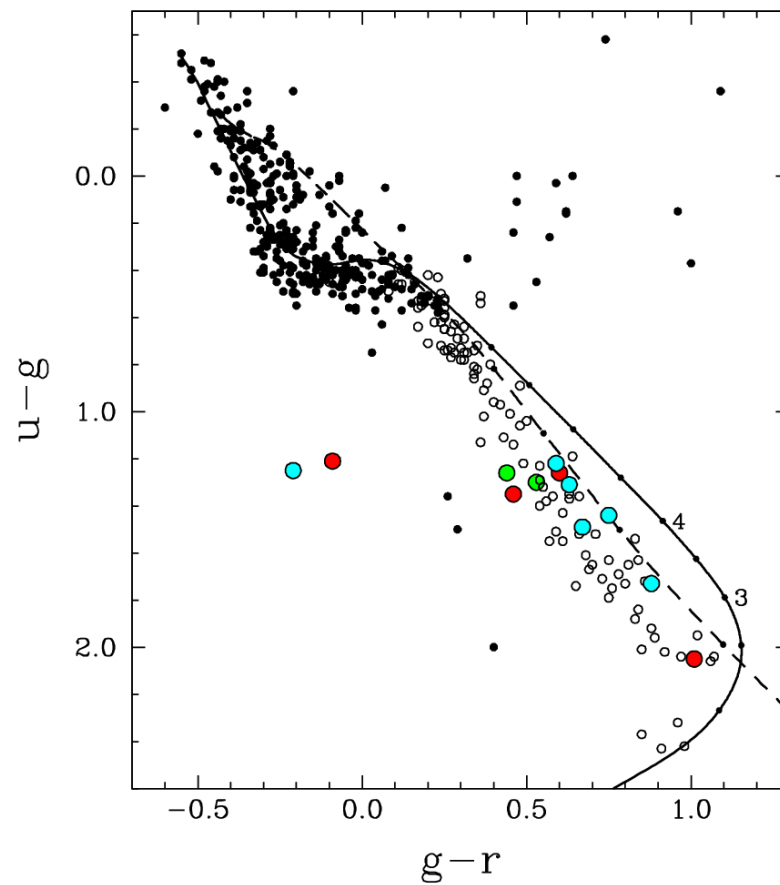
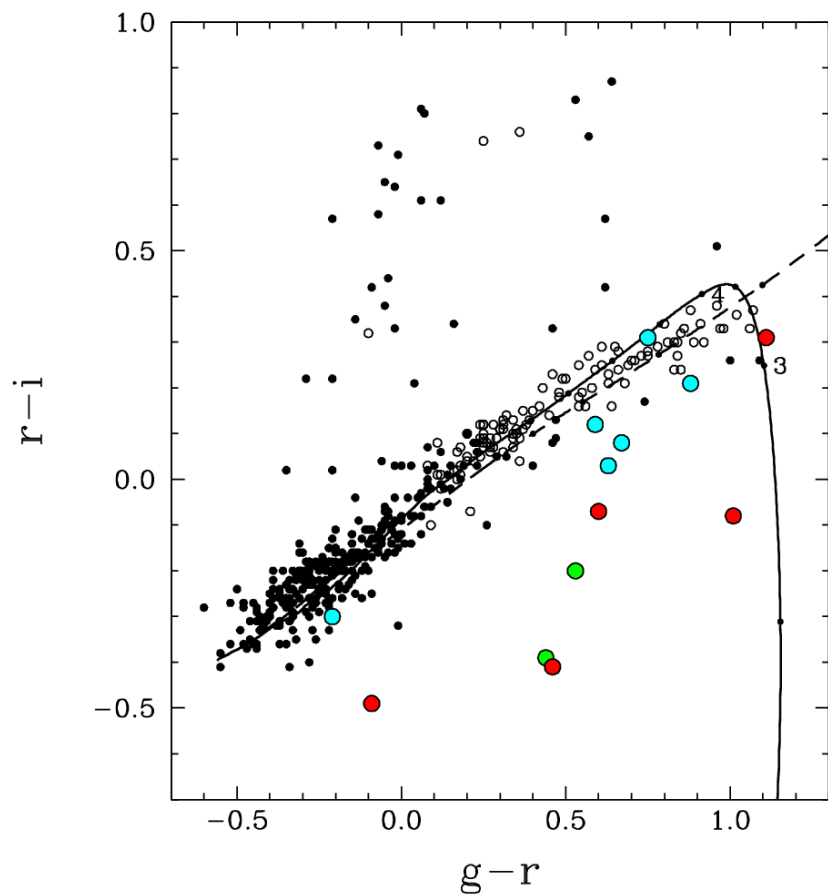
Harris et al. (2008)



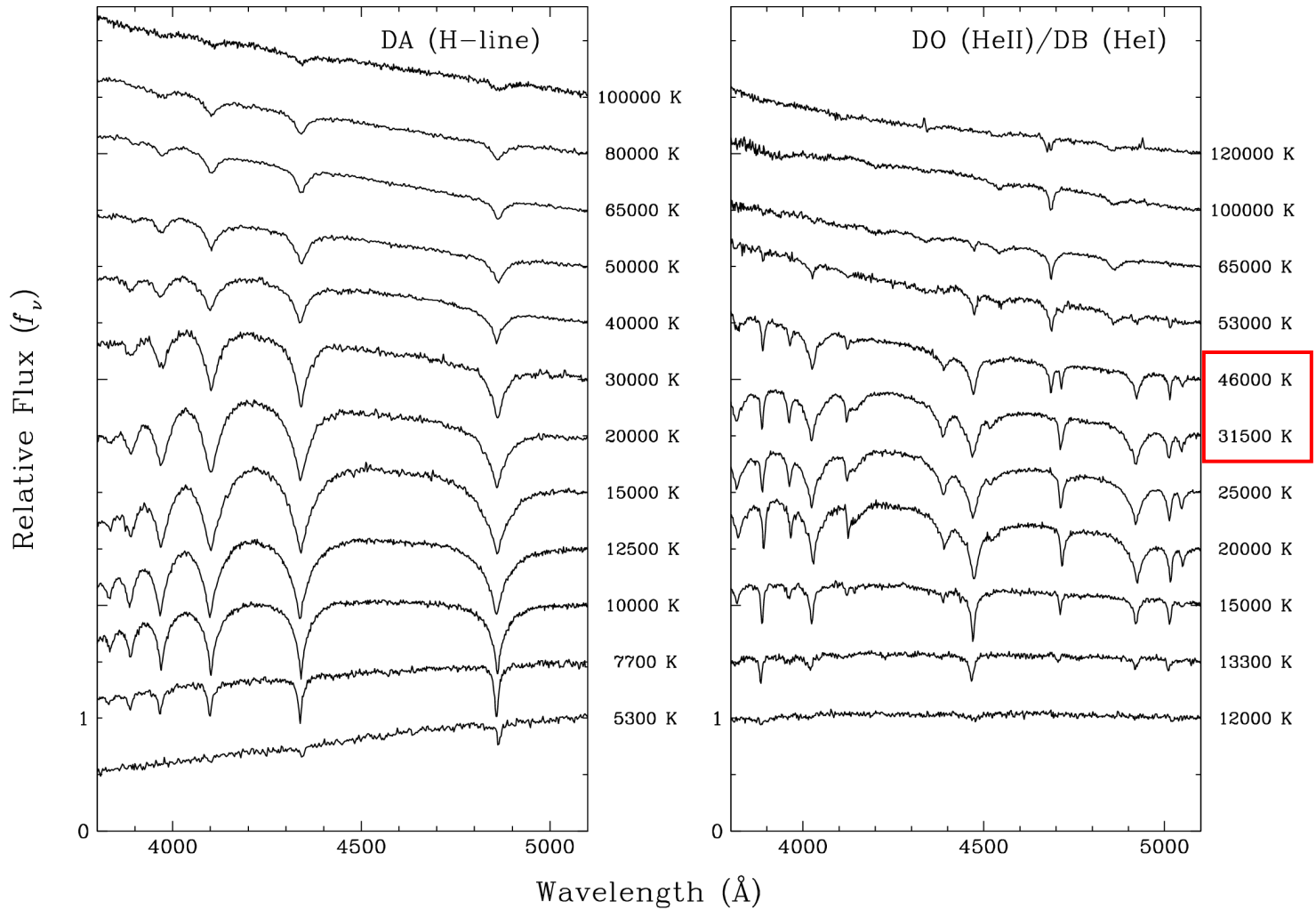
● SDSS 1337 & LHS 3250

● Gates et al. (2004)

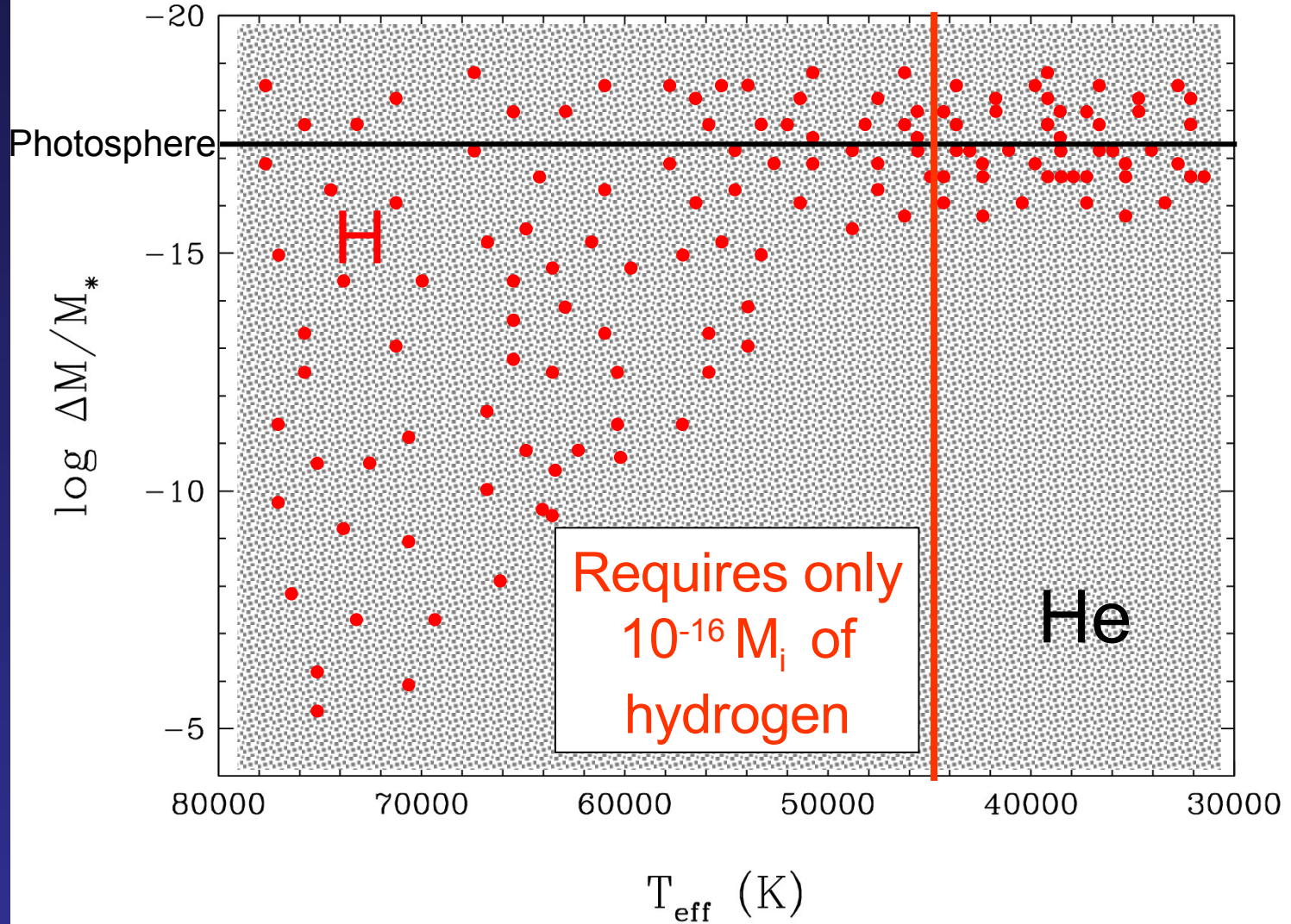
● Harris et al. (2008)



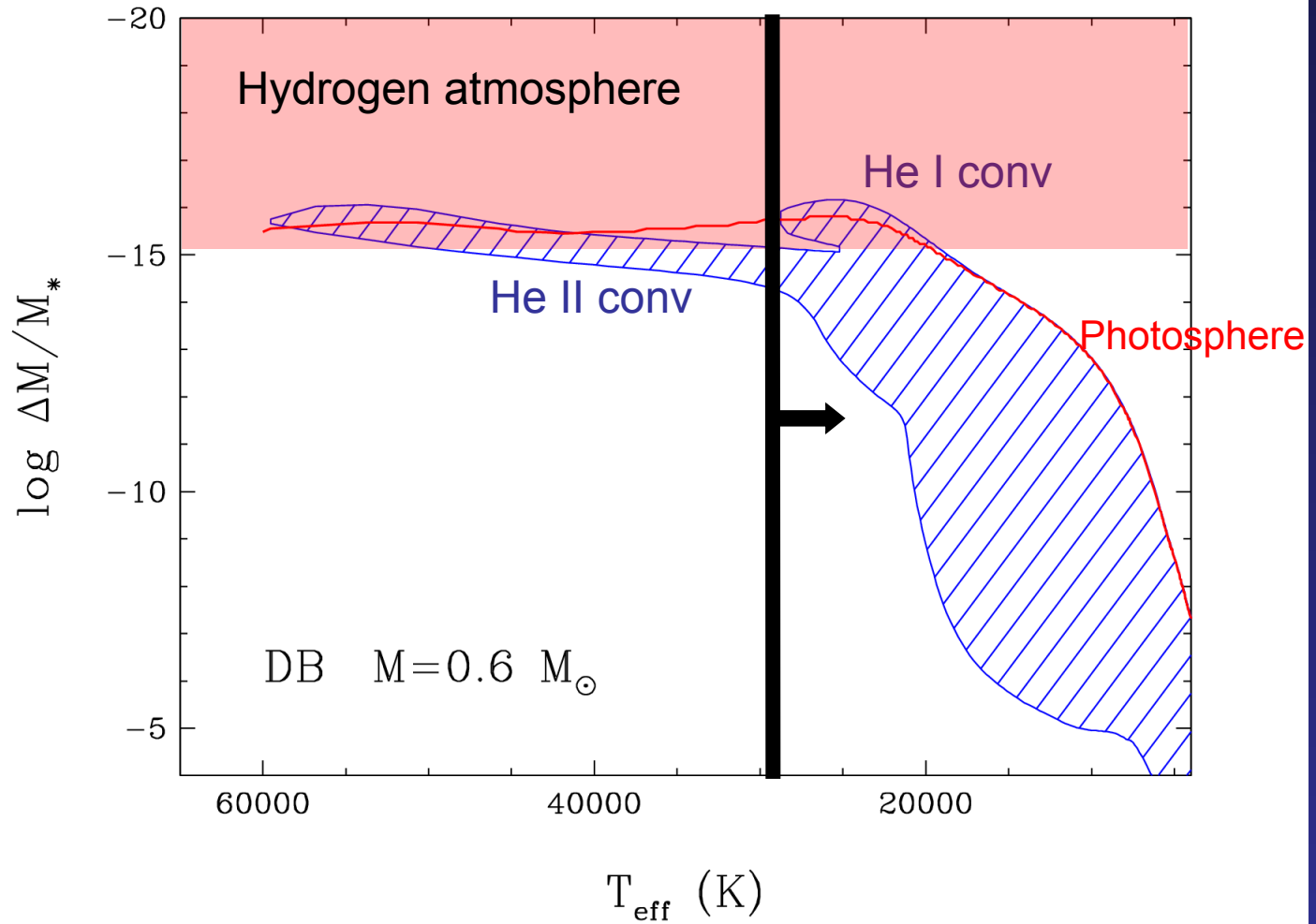
DB white dwarfs in the «DB gap»



DO \longrightarrow DA DB?



DA → DB



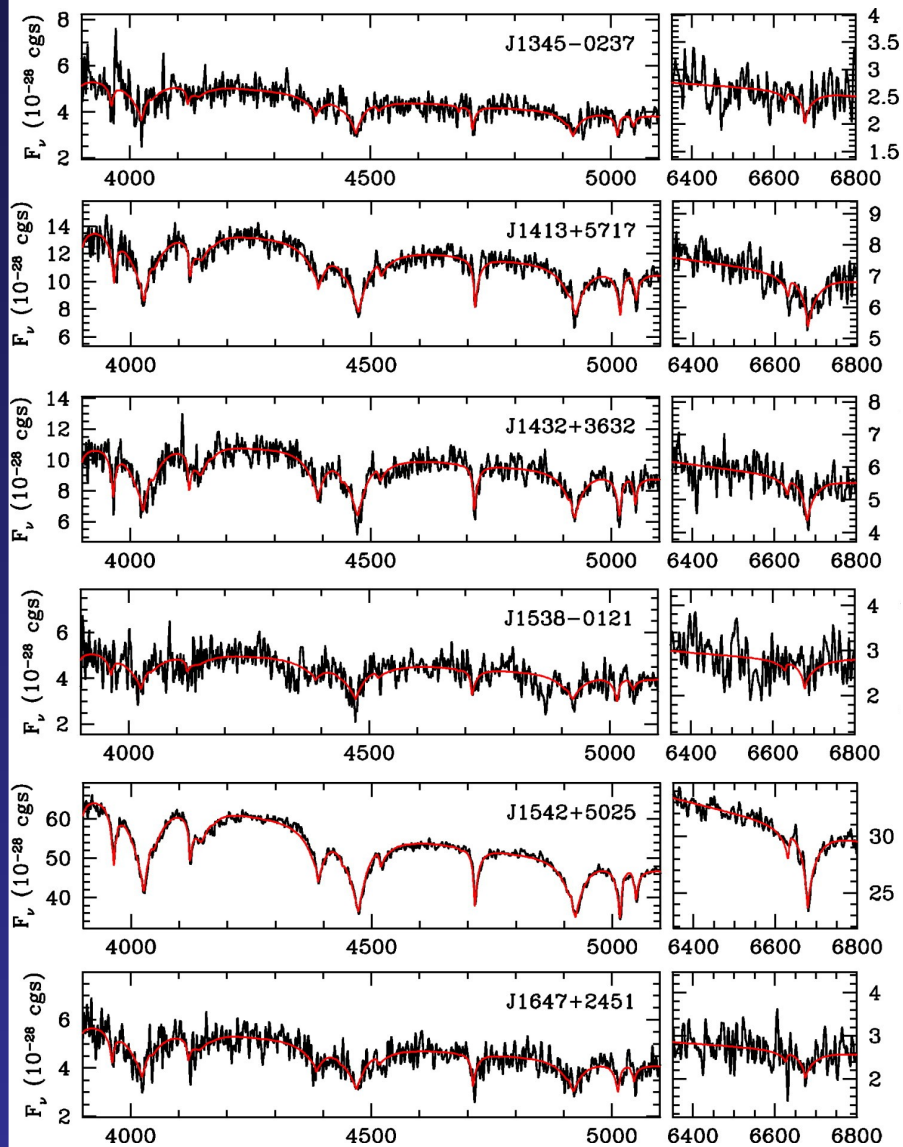
«convective dilution»

HOT DB WHITE DWARFS FROM THE SLOAN DIGITAL SKY SURVEY¹

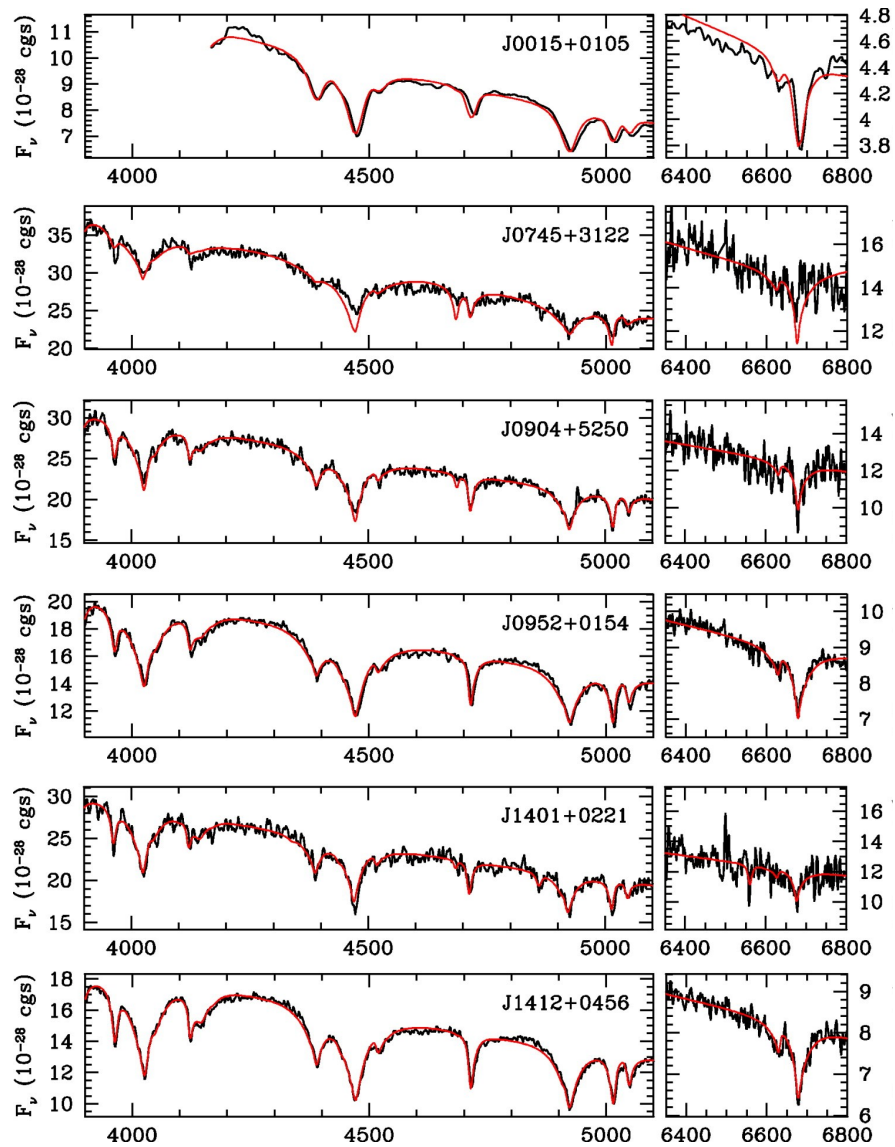
DANIEL J. EISENSTEIN,^{2,3} JAMES LIEBERT,² DETLEV KOESTER,⁴ S. J. KLEINMANN,^{5,6} ATSUKO NITTA,^{5,6} PAUL S. SMITH,²
J. C. BARENTINE,⁵ HOWARD J. BREWINGTON,⁵ J. BRINKMANN,⁵ MICHAEL HARVANEK,⁵ JUREK KRZESIŃSKI,^{5,7}
ERIC H. NEILSEN, JR.,⁸ DAN LONG,⁵ DONALD P. SCHNEIDER,⁹ AND STEPHANIE A. SNEDDEN⁵

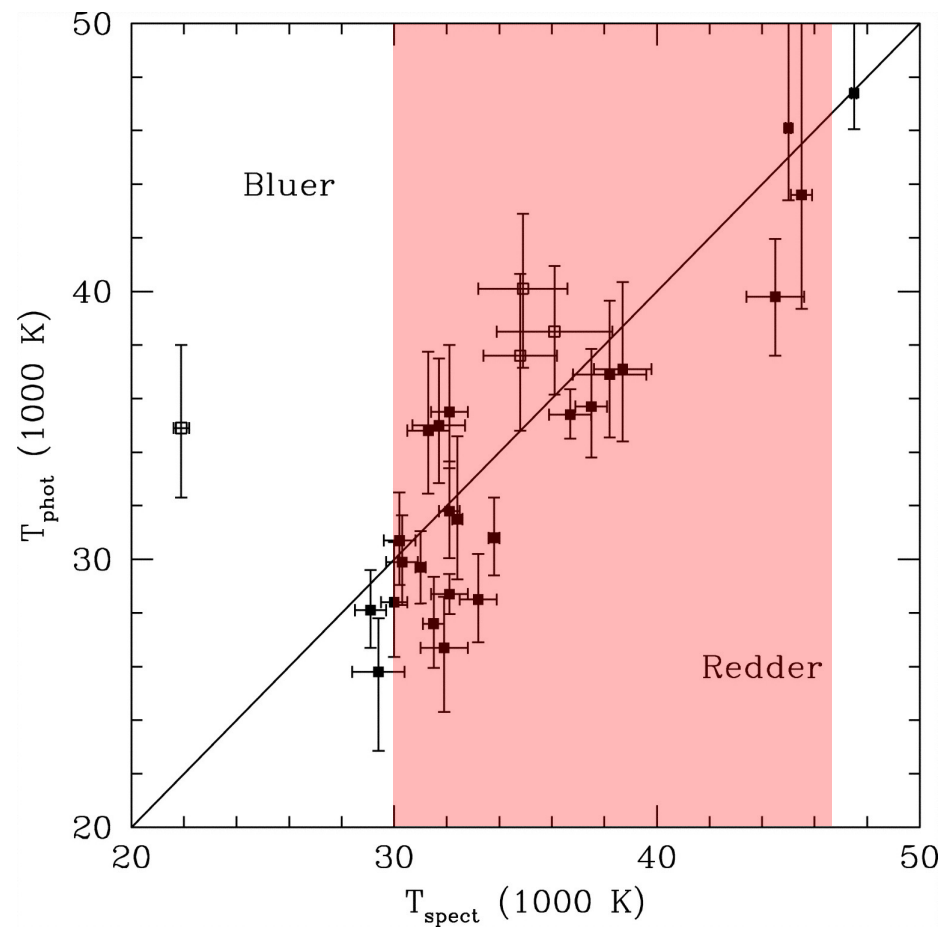
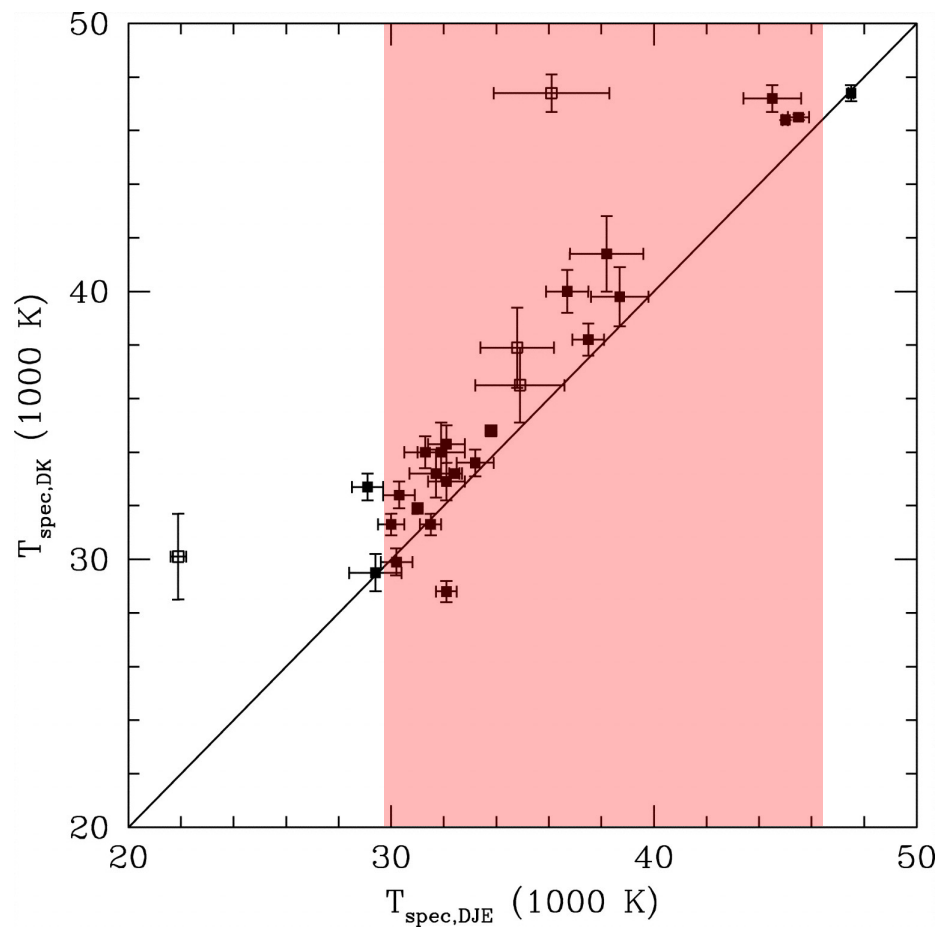
Received 2005 December 29; accepted 2006 March 18

SDSS



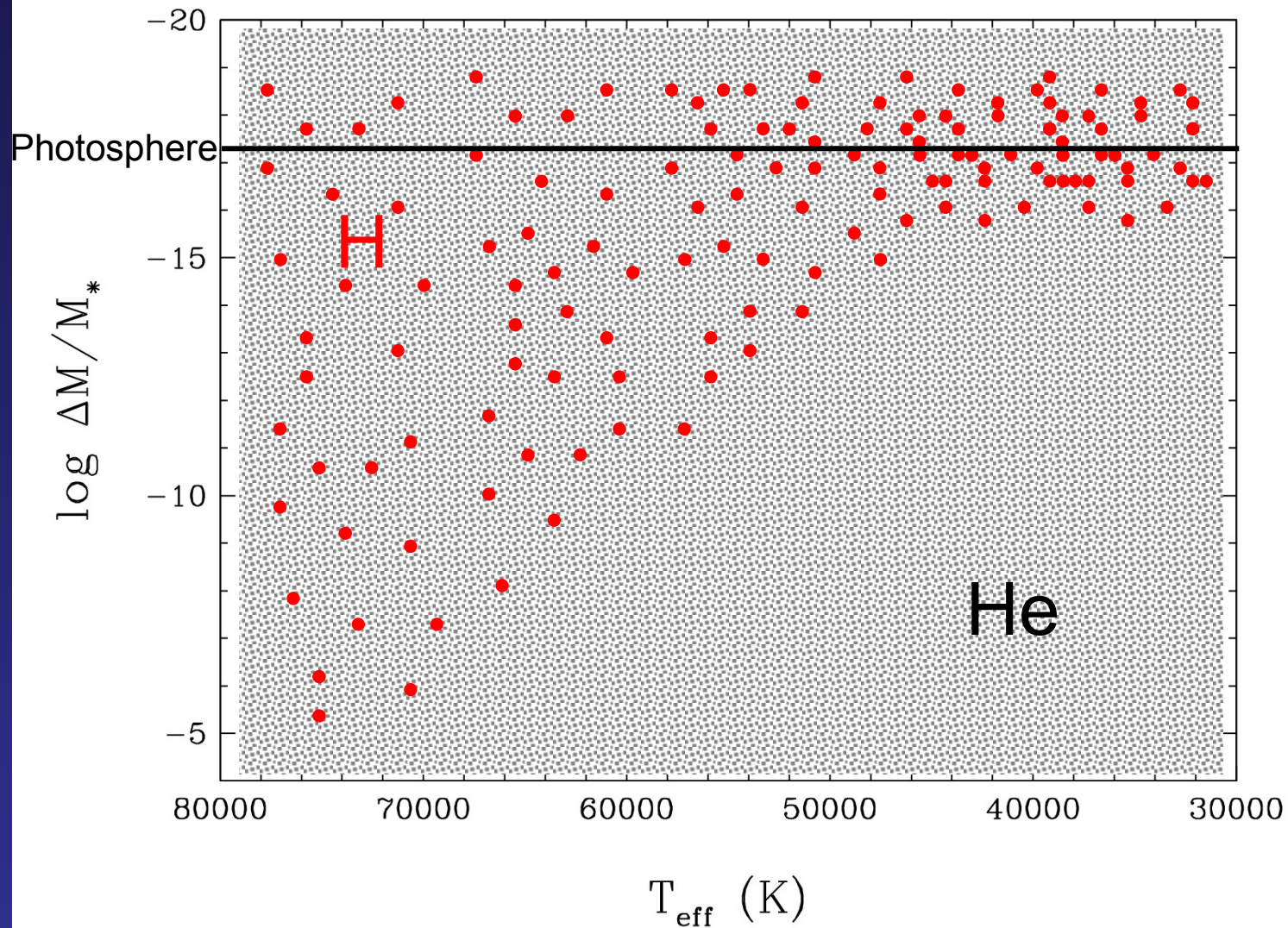
MMT





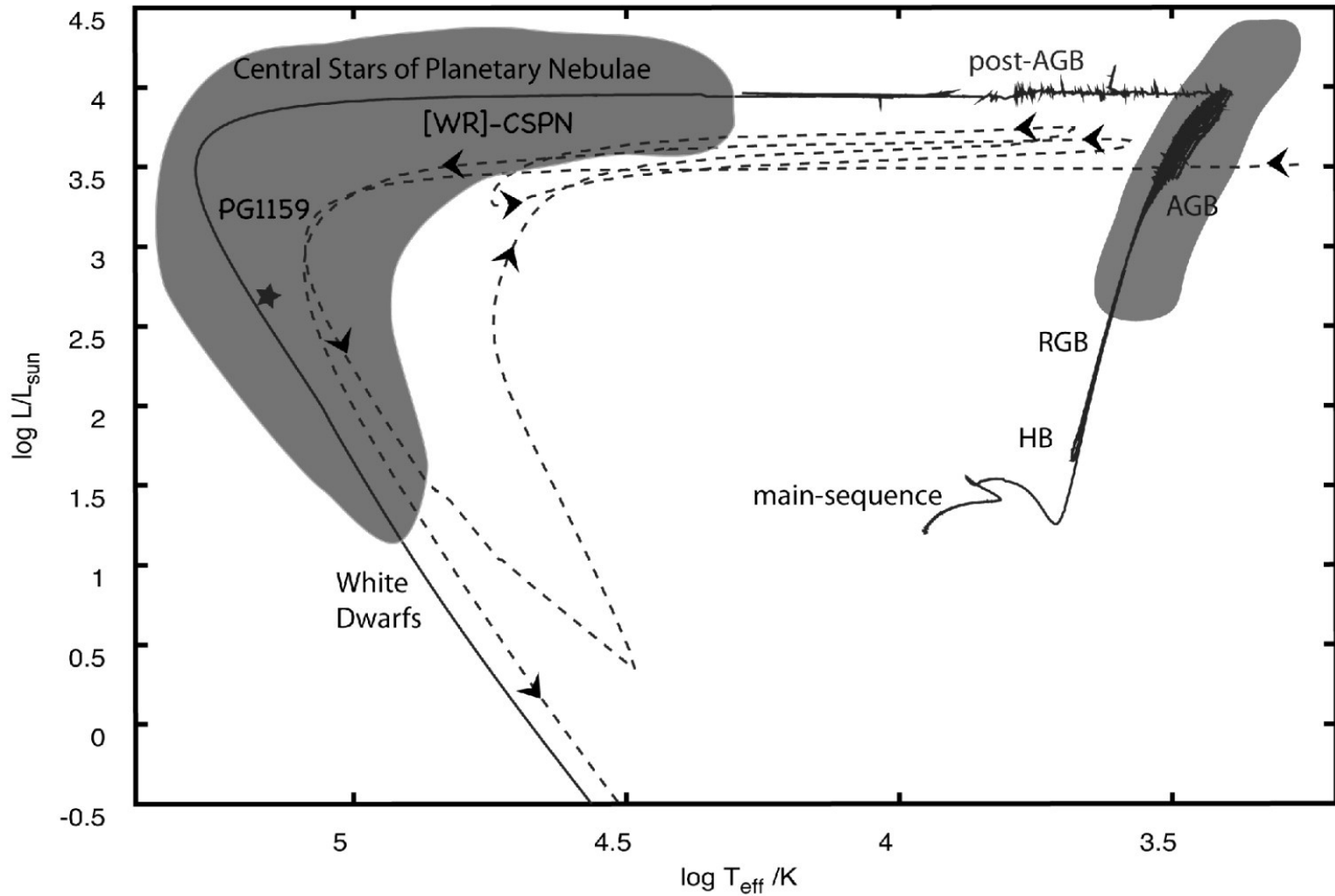
There are DB stars in the gap !

No hydrogen left after the post-AGB phase !



"Born-Again scenario"

Werner & Herwig (2006)



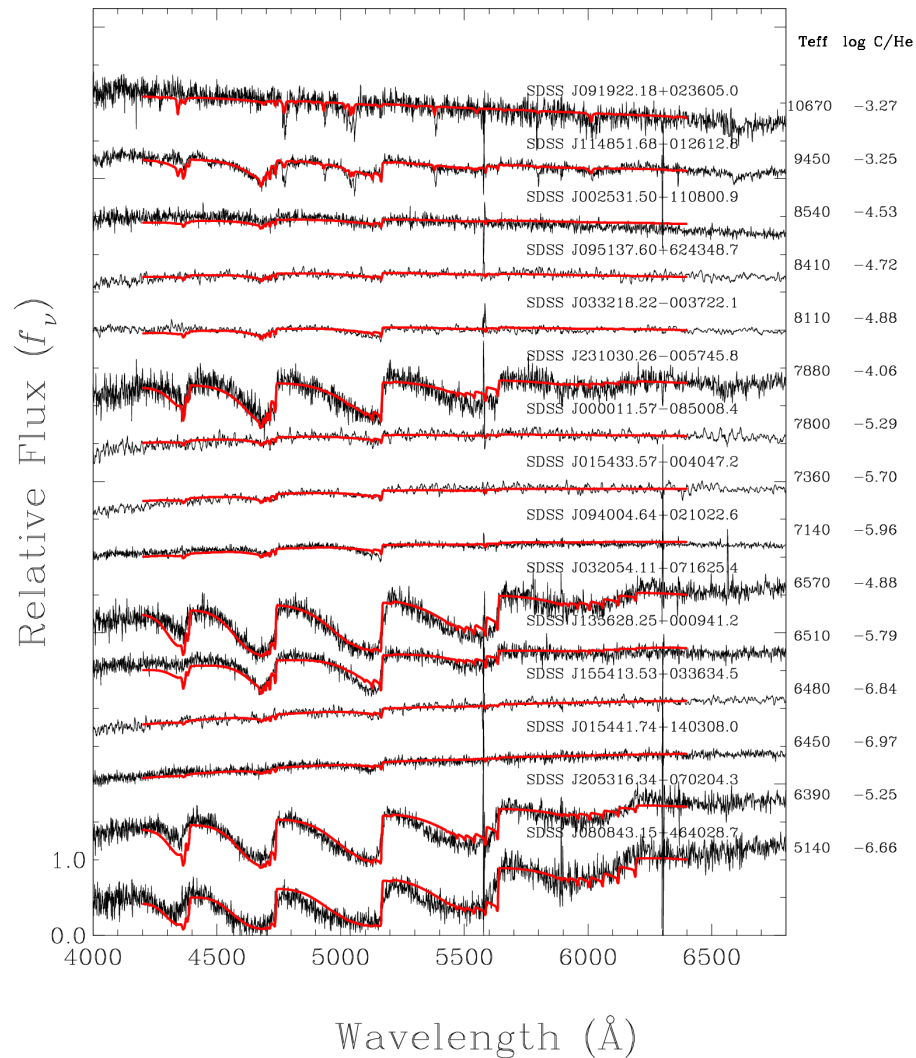
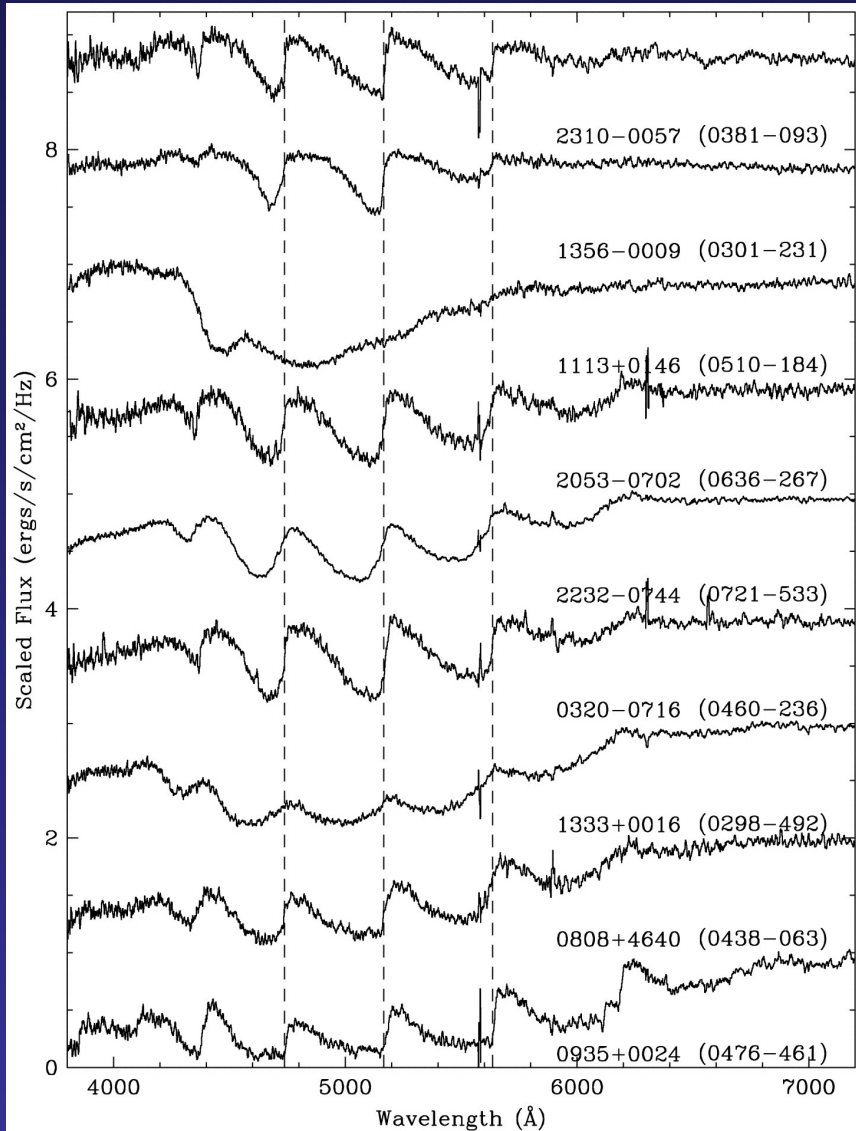
DQ white dwarfs

THE ASTROPHYSICAL JOURNAL, 627:404–417, 2005 July 1

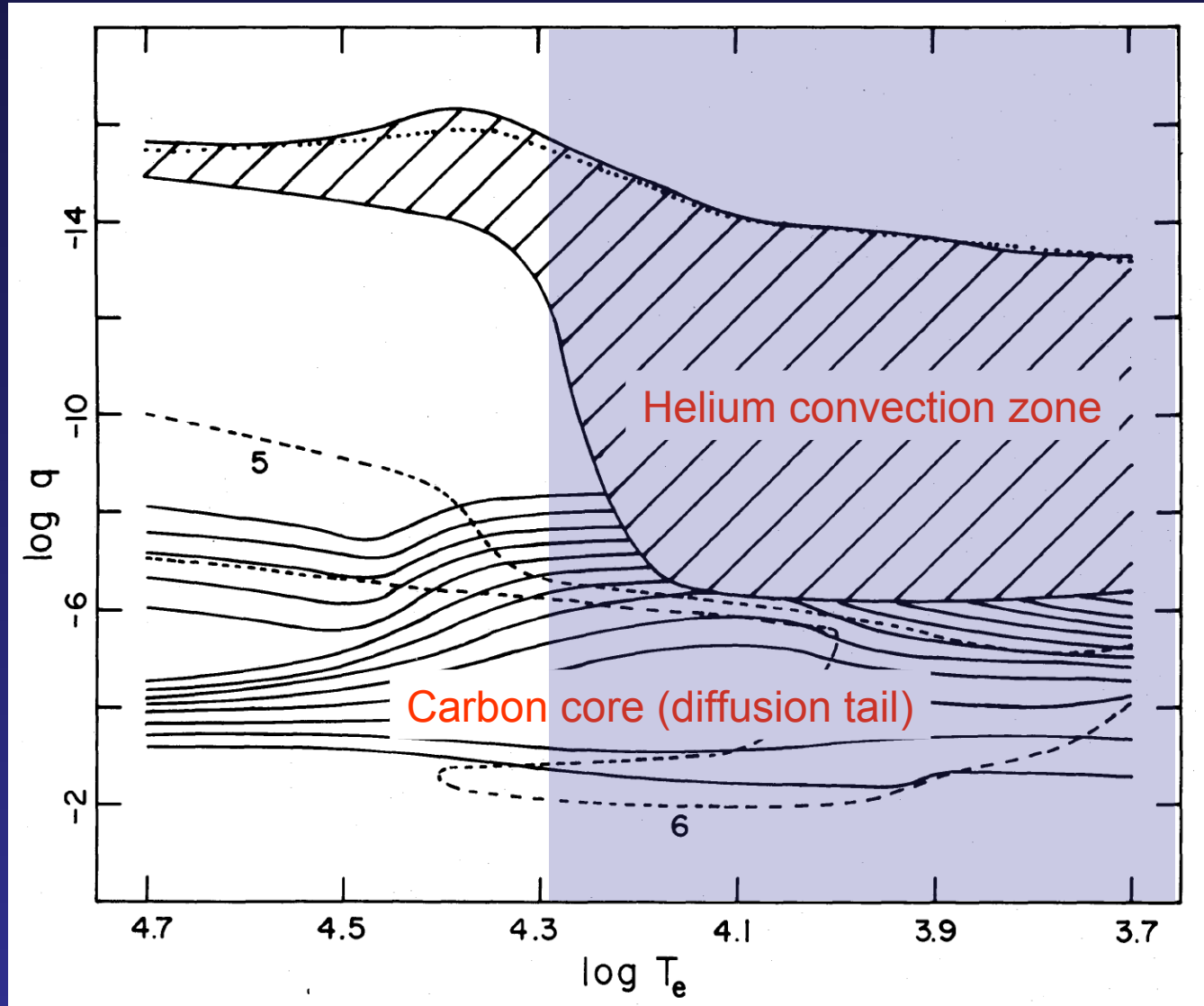
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DETAILED SPECTROSCOPIC AND PHOTOMETRIC ANALYSIS OF DQ WHITE DWARFS

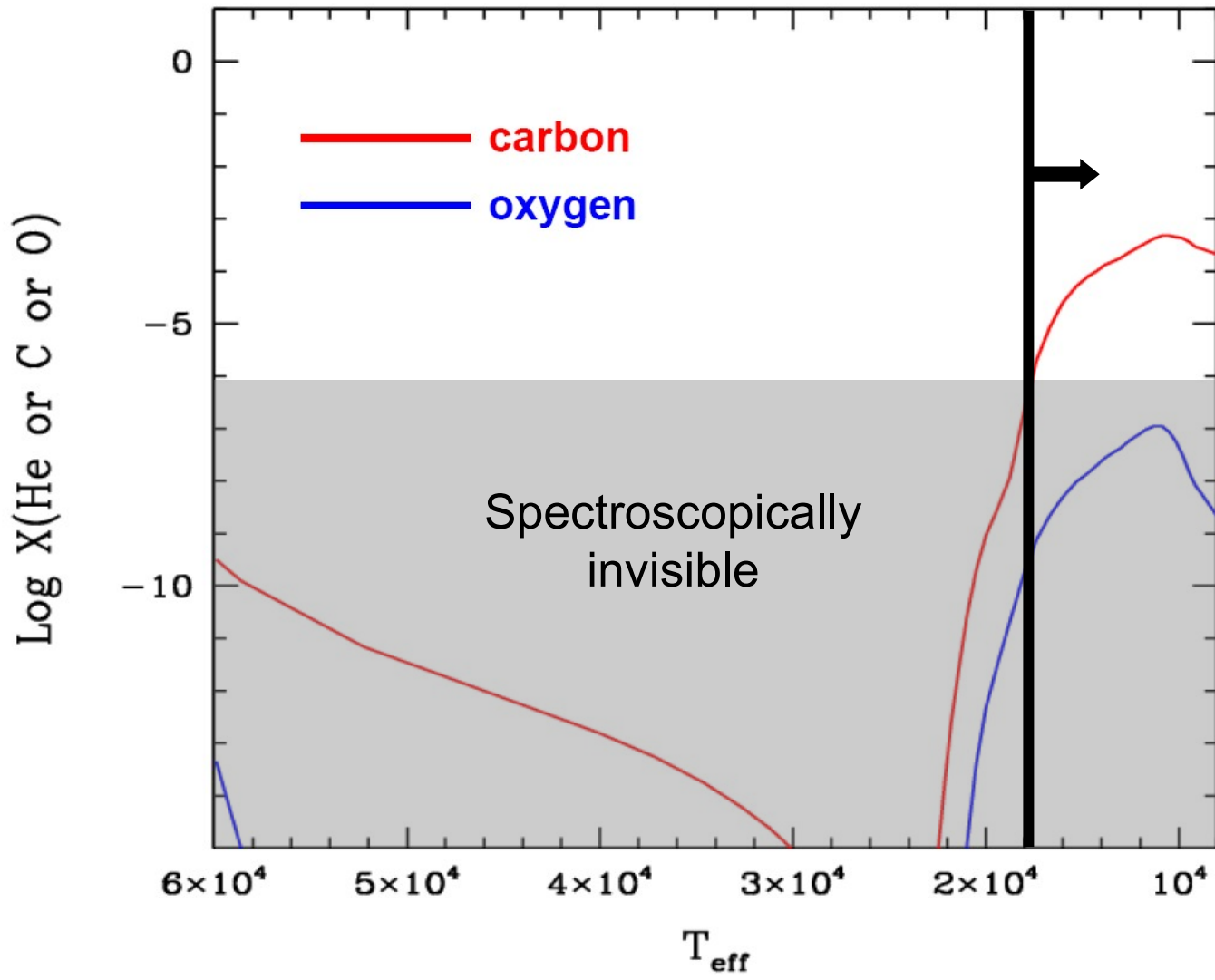
P. DUFOUR, P. BERGERON, AND G. FONTAINE



The origin of carbon in DQ stars



Carbon in DQ stars is being dredged up from the core



SDSS WHITE DWARFS WITH SPECTRA SHOWING ATOMIC OXYGEN AND/OR CARBON LINES

JAMES LIEBERT,¹ H. C. HARRIS,² C. C. DAHN,² GARY D. SCHMIDT,³ S. J. KLEINMAN,⁴ ATSUKO NITTA,⁴
JUREK KRZESIŃSKI,^{4,5} DANIEL EISENSTEIN,¹ J. ALLYN SMITH,⁶ PAULA SZKODY,⁷ SUZANNE HAWLEY,⁷
SCOTT F. ANDERSON,⁷ J. BRINKMANN,⁴ MATTHEW J. COLLINGE,⁸ XIAOHUI FAN,¹ PATRICK B. HALL,^{8,9}
GILLIAN R. KNAPP,⁸ DON Q. LAMB,¹⁰ B. MARGON,¹¹ DONALD P. SCHNEIDER,¹² AND NICOLE SILVESTRI⁷

Received 2003 July 11; accepted 2003 August 6

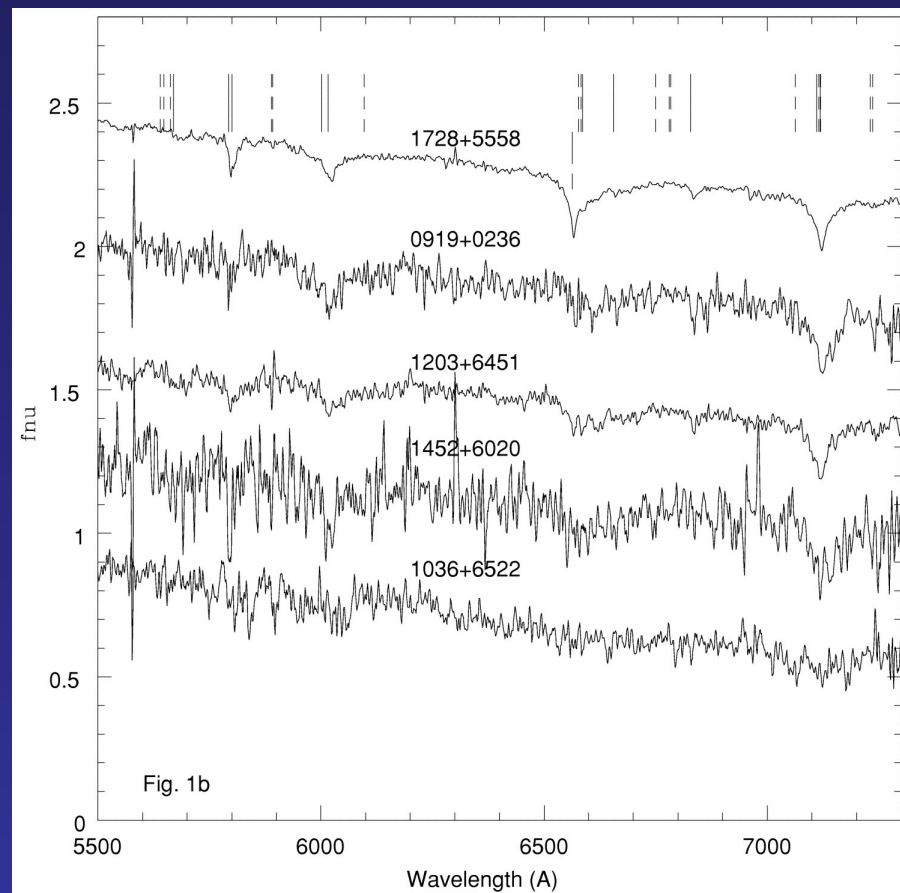
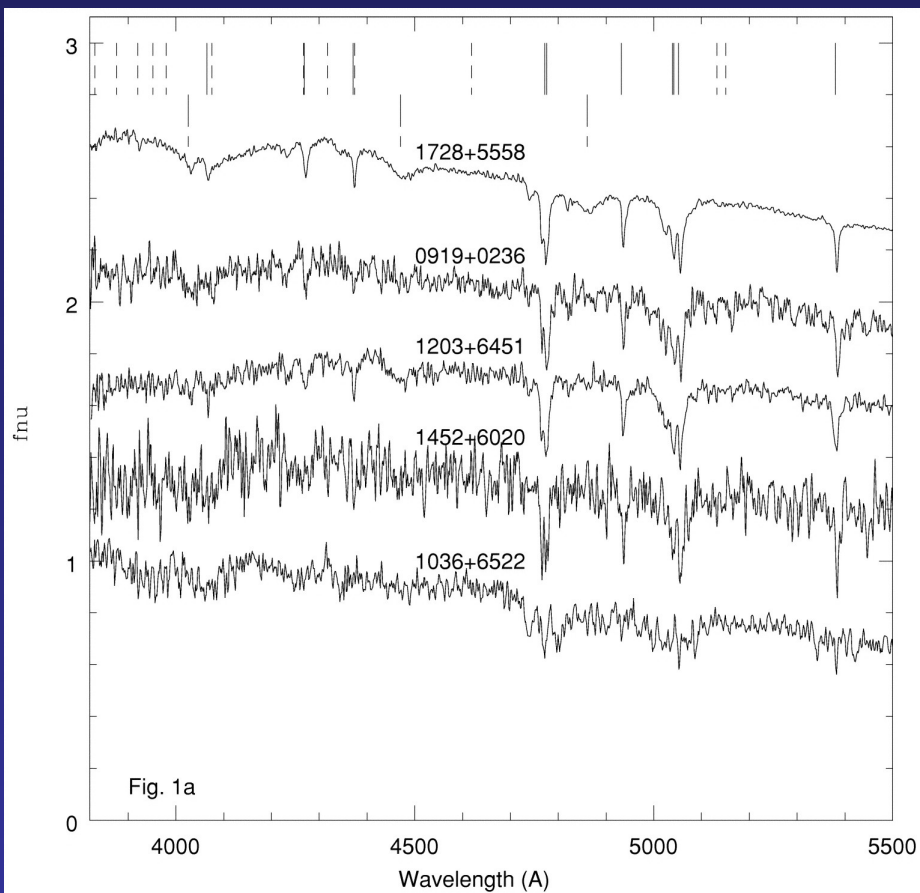
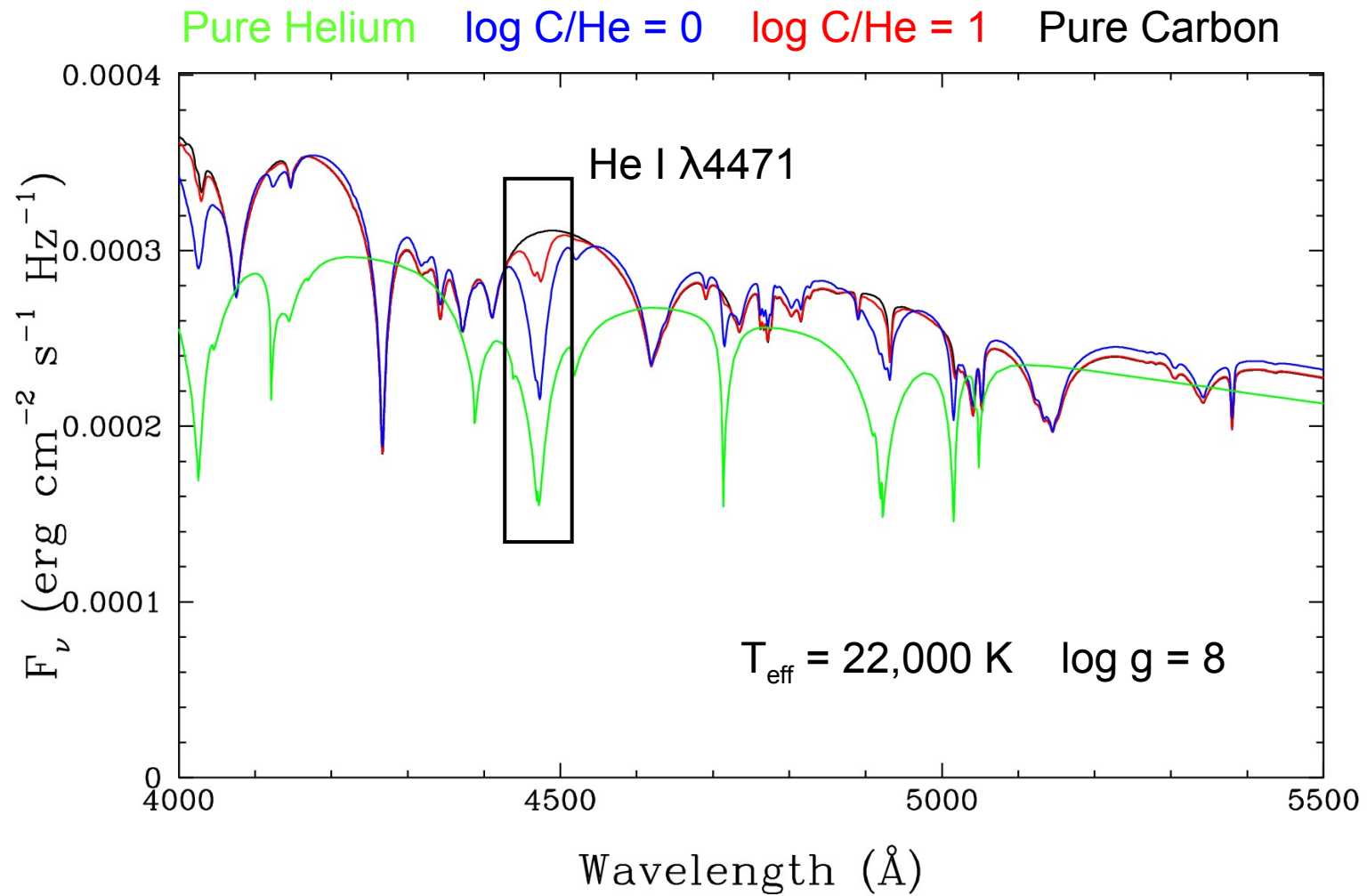


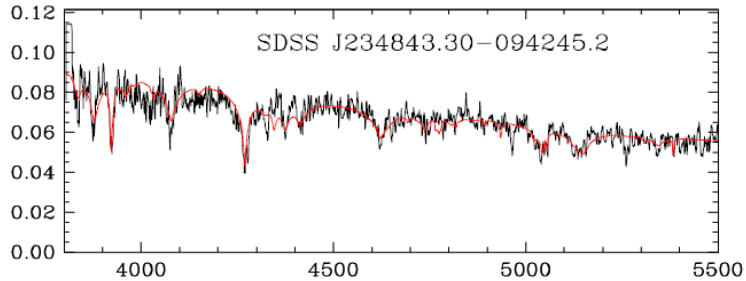
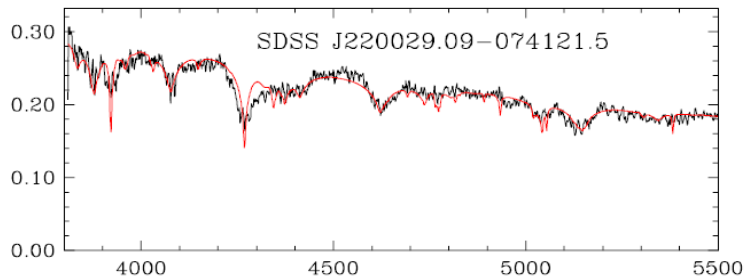
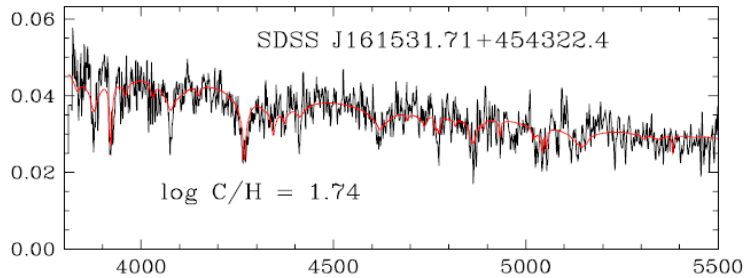
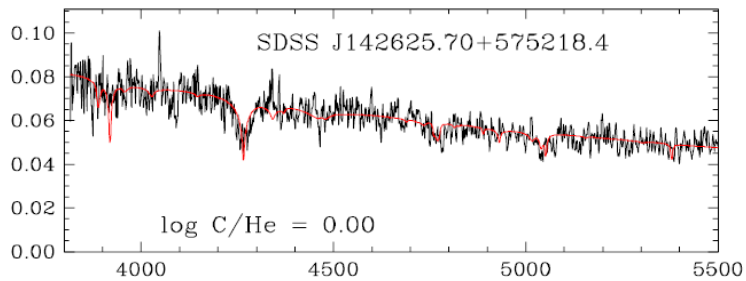
TABLE 1
LIST OF HOT CARBON WHITE DWARFS

| SDSSJ | Name SDSSJ+ | $g-i$ | T_{He} | A_u | b^{II} | μ | P.A. | Spec. |
|----------------|--------------------|-------|-----------------|-------|-----------------|-------|-------|---------------------------|
| 0005-1002..... | 000555.91-100213.4 | -0.76 | 29 | 0.189 | -69.80 | 84.7 | 77.9 | DQ (C II, mag?) |
| 0106+1513..... | 010647.93+151327.9 | -0.65 | 20 | 0.331 | -47.48 | 34.5 | 214.5 | DQ (C II, O II?) |
| 0236-0734..... | 023637.43-073429.5 | -0.77 | 30 | 0.144 | -58.32 | 0.0 | ... | DQ (C II, C I?) |
| 0749+3540..... | 074947.00+354055.5 | -0.67 | 21 | 0.212 | +26.88 | 40.2 | 61.5 | DQA (C I, H) |
| 0901+5751..... | 090157.92+575135.9 | -0.53 | 15 | 0.148 | +39.90 | 63.4 | 83.6 | DQ (C I, O I) |
| 0919+0236..... | 091922.18+023605.0 | -0.41 | 12.5 | 0.209 | +33.75 | 121.2 | 127.6 | DQ (C I) |
| 1036+6522..... | 103655.38+652252.1 | -0.63 | 18 | 0.068 | +46.32 | 17.6 | 91.4 | DQ (C I, mag) |
| 1133+6331..... | 113359.94+633113.2 | -0.45 | 13.5 | 0.172 | +51.50 | 174.9 | 202.5 | DQ (C I) |
| 1148-0126..... | 114851.68-012612.8 | -0.20 | 10 | 0.099 | +57.71 | 150.8 | 208.8 | DQ (C I, C ₂) |
| 1153+0056..... | 115305.54+005646.2 | -0.75 | 28 | 0.104 | +60.31 | 147.2 | 250.0 | DQ (C I, C II) |
| 1203+6451..... | 120331.90+645101.3 | -0.50 | 14 | 0.104 | +51.51 | 152 | 204.0 | DQ (C I) |
| 1328+5908..... | 132858.20+590851.0 | -0.67 | 21 | 0.067 | +57.33 | 92 | 267.0 | DQ (C I, C II, O II?) |
| 1337-0026..... | 133710.20-002643.8 | -0.81 | >30 | 0.143 | +60.31 | 6.6 | 109.3 | DQ (C I, C II) |
| 1423+5729..... | 142342.64+572949.3 | -0.40 | 12.5 | 0.040 | +55.54 | 65 | 178.9 | DQ (C I, O I) |
| 1444+0434..... | 144407.25+043446.8 | -0.23 | 10 | 0.149 | +54.93 | 37.6 | 142.9 | DQ (C I, C ₂) |
| 1452+6020..... | 145236.58+602036.3 | -0.54 | 16 | 0.054 | +50.94 | 81.5 | 298.3 | DQ (C I) |
| 1711+2831..... | 171120.47+283135.1 | -0.70 | 24 | 0.250 | +33.27 | 42 | 195.1 | DQA (C I, H?) |
| 1728+5558..... | 172856.23+555822.8 | -0.59 | 17 | 0.191 | +33.60 | 256.1 | 333.9 | DBQA (C I, H, He I) |

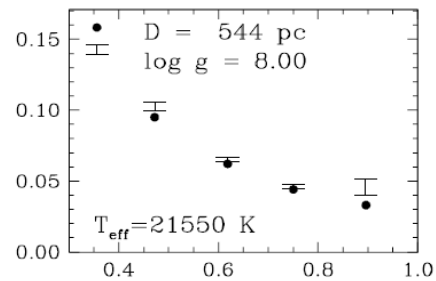
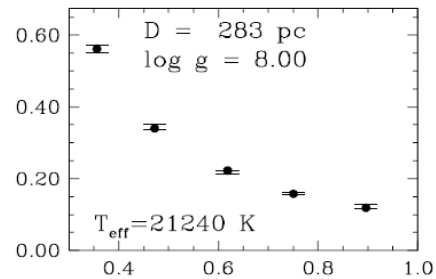
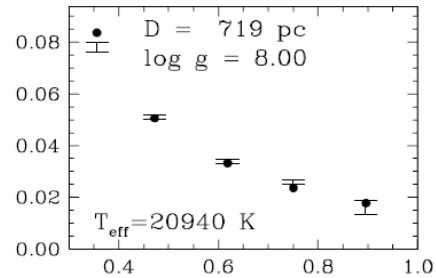
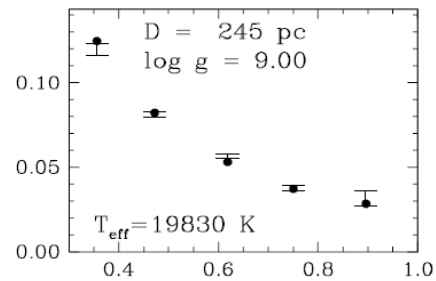


Courtesy of Patrick Dufour (Steward Observatory)

f_ν (10^{-26} erg cm^{-2} s^{-1} Hz^{-1})



Wavelength (\AA)



Wavelength (μm)

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Letter

Nature 450, 522-524 (22 November 2007) | doi:10.1038/nature06318; Received 31 July 2007; Accepted 12 September 2007

White dwarf stars with carbon atmospheres

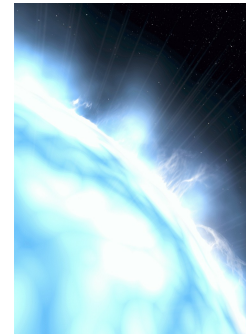
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arXiv:0805.0331v1 [astro-ph] 3 May 2008

Hot DQ White Dwarfs: Something Different

P. Dufour¹, G. Fontaine², James Liebert¹, G. D. Schmidt¹, N. Behara³



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Atmosfere al carbonio

di Claudio Elidoro - Fonte: University of Ariz

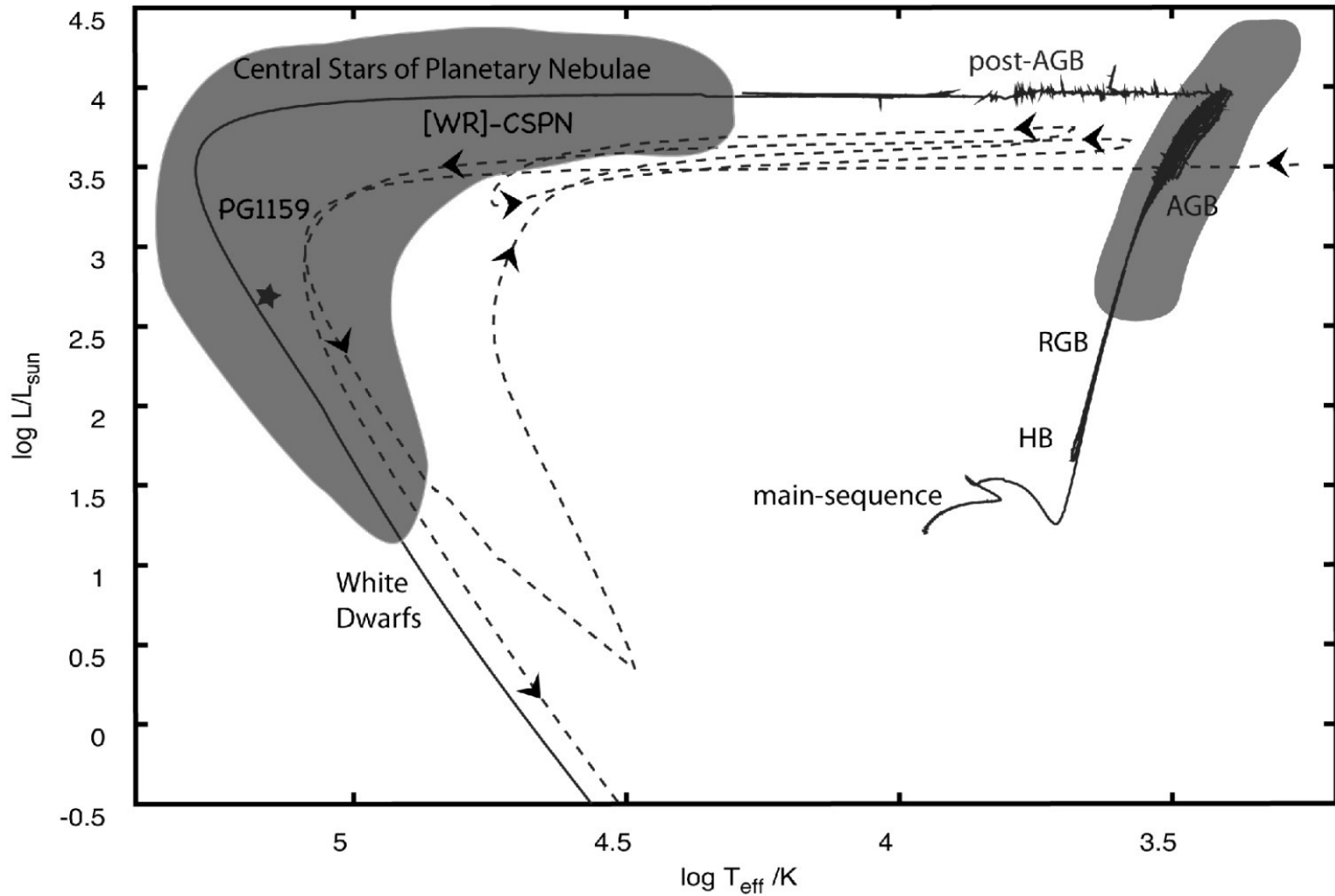


Alle ormai i
hanno potu
Survey (SD
Questa volt
gli astrofisici che si occupano di evoluzione stellare e
la scoperta riguarda lo stadio estremo delle stelle di
piccola massa, quello di nana bianca.
Già nel 2003 alcune tra le 10 mila nuove nane
bianche messe allo scoperto dalla SDSS avevano
attirato l'attenzione degli astrofisici. Qualche dozzina
di esse, infatti, aveva mostrato di possedere
un'atmosfera differente da quella solitamente
osservata in tali astri e per questo motivo si era
introdotta un'apposita tipologia, quelle delle nane
bianche di tipo "SQ". La loro atmosfera non si presentava come la classica miscela di
idrogeno ed elio, ma era caratterizzata da un'anomala abbondanza di carbonio.



"Born-Again scenario"

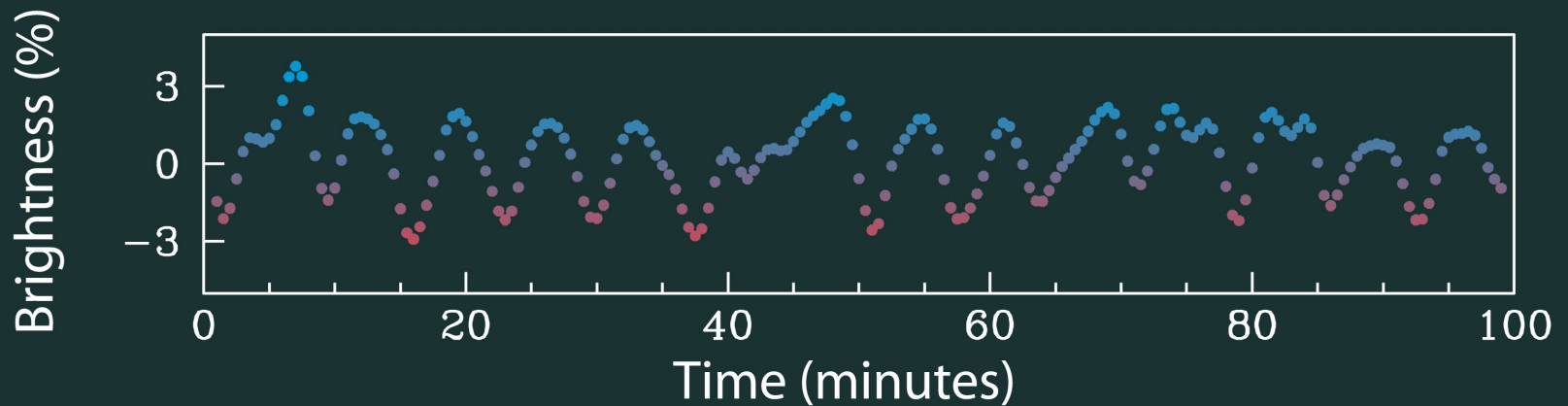
Werner & Herwig (2006)



SDSS J142625.71+575218.3: A PROTOTYPE FOR A NEW CLASS OF VARIABLE WHITE DWARF

M. H. MONTGOMERY,¹ KURTIS A. WILLIAMS,^{1,2} D. E. WINGET,¹ PATRICK DUFOUR,³
STEVEN DEGENNARO,¹ AND JAMES LIEBERT³

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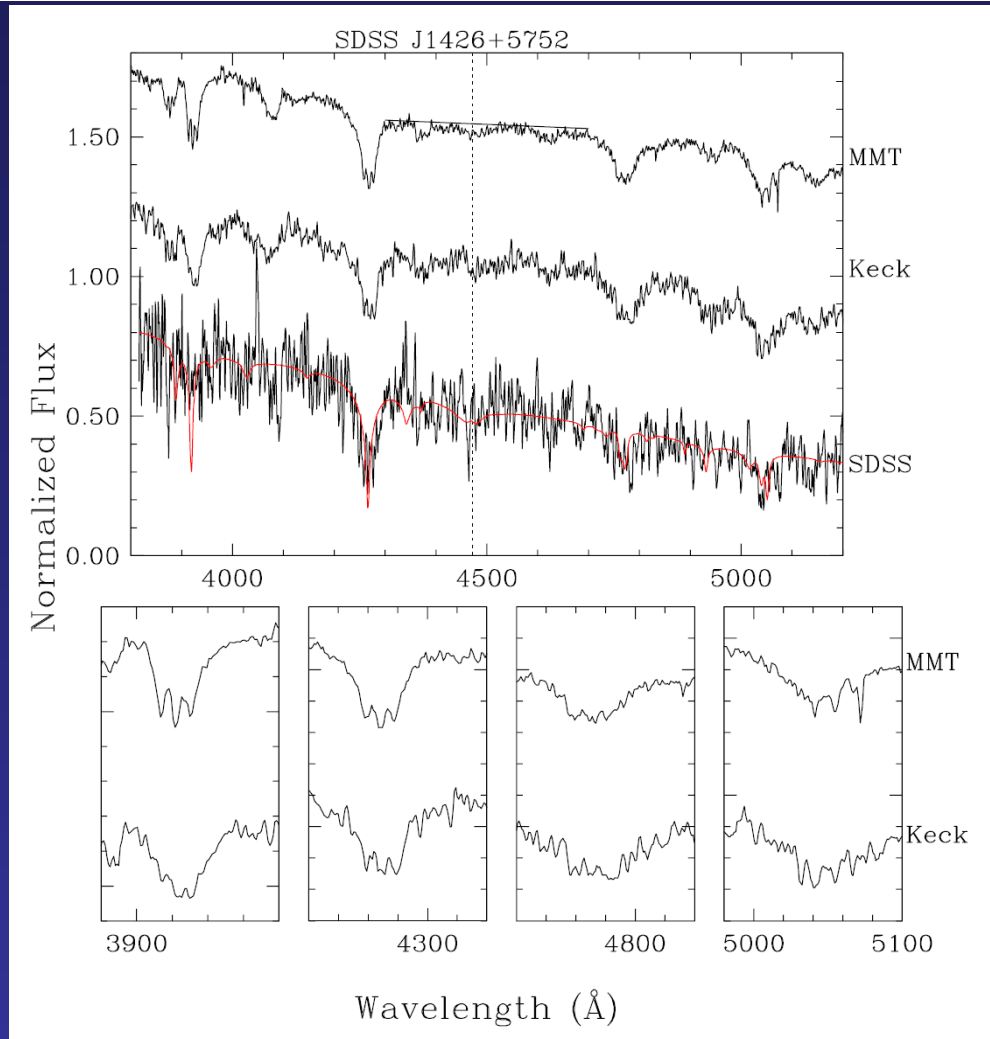


A new chapter in white dwarf asteroseismology

SDSS J142625.71+575218.3: THE FIRST PULSATING WHITE DWARF WITH A LARGE DETECTABLE MAGNETIC FIELD

P. DUFOUR¹, G. FONTAINE², JAMES LIEBERT¹, KURTIS WILLIAMS^{3,4}, DAVID K. LAI⁵,

Draft version July 7, 2008



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