Spectroscopic studies of white dwarf stars

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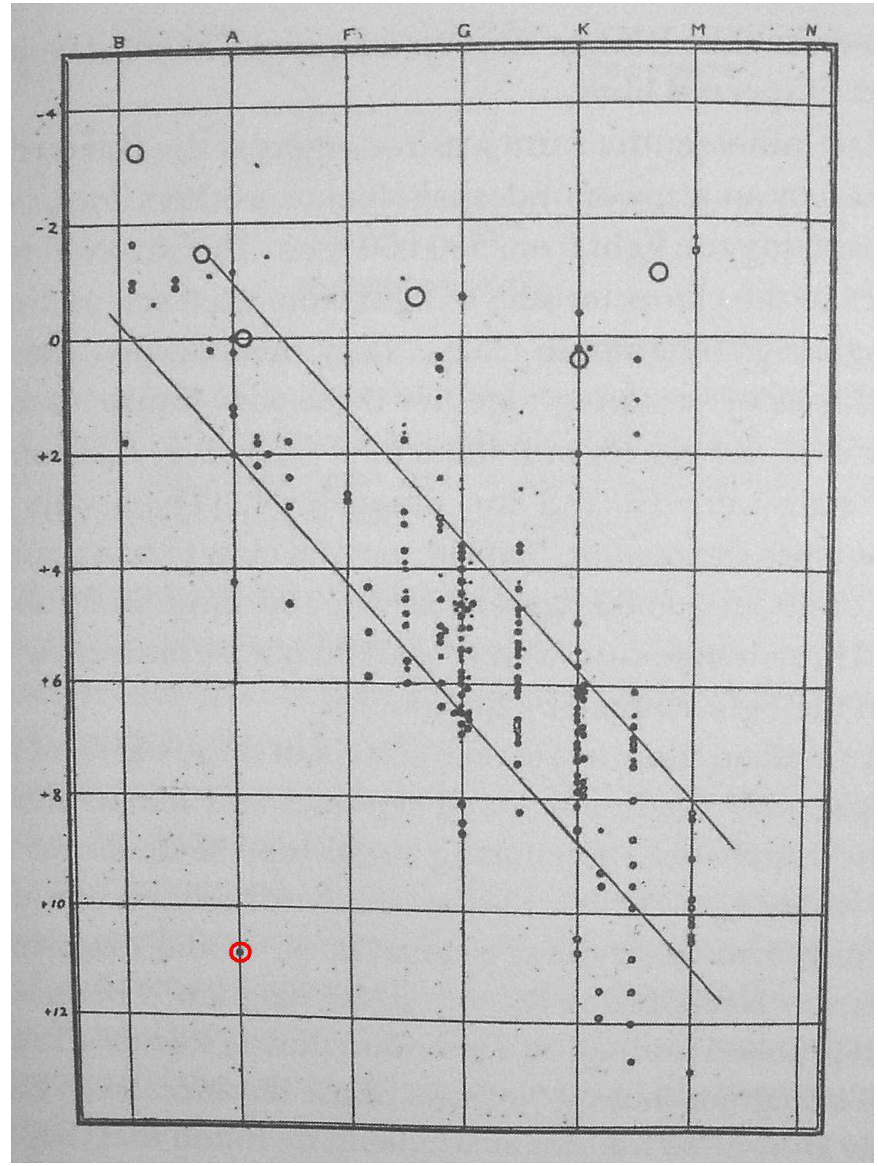
Motivation

- to extend the number of known white dwarfs to the distance of $\sim$ 20 pc from the Sun; nowadays complete sample to about 13 pc (Holberg et al., 2008)
- to determine properties of white dwarfs in the Solar neighborhood
- proposed plan of work:
  - choice of candidates from rNLTT (Revised New Luyten Two-Tenths) catalog
  - study of literature concerning these objects
  - determination of atmospheric parameters of unknown white dwarfs
  - acquisition of further properties of white dwarfs

History of discovery

- H.N. Russell (1914)
  – 40 Eridani B
- A. van Maanen (1917)
  – van Maanen 2
- A. Clark (1862)
  – Sirius B



Properties of white dwarfs

- 90% of stars will evolve into a white dwarf
- enormous densities in the range from 10^6 g$\cdot$cm^{-3} up to 10^9 g$\cdot$cm^{-3}
- small radii $\sim$ 1% of radius of the Sun
- temperatures in the range from $\sim$ 100 000 K up to about 3 000 K
- cooling age approximately 10^{10} years
- masses in the range from 0.4 $M_\odot$ up to 1.2 $M_\odot$
- rotational velocities less than 40 km$\cdot$s^{-1}
- magnetic field have approximately 20% of white dwarfs in the Solar neighbourhood, the strength of the field ranges from $\sim$ 1 kG up to 1000 MG

- spectral classification:

DA Balmer lines

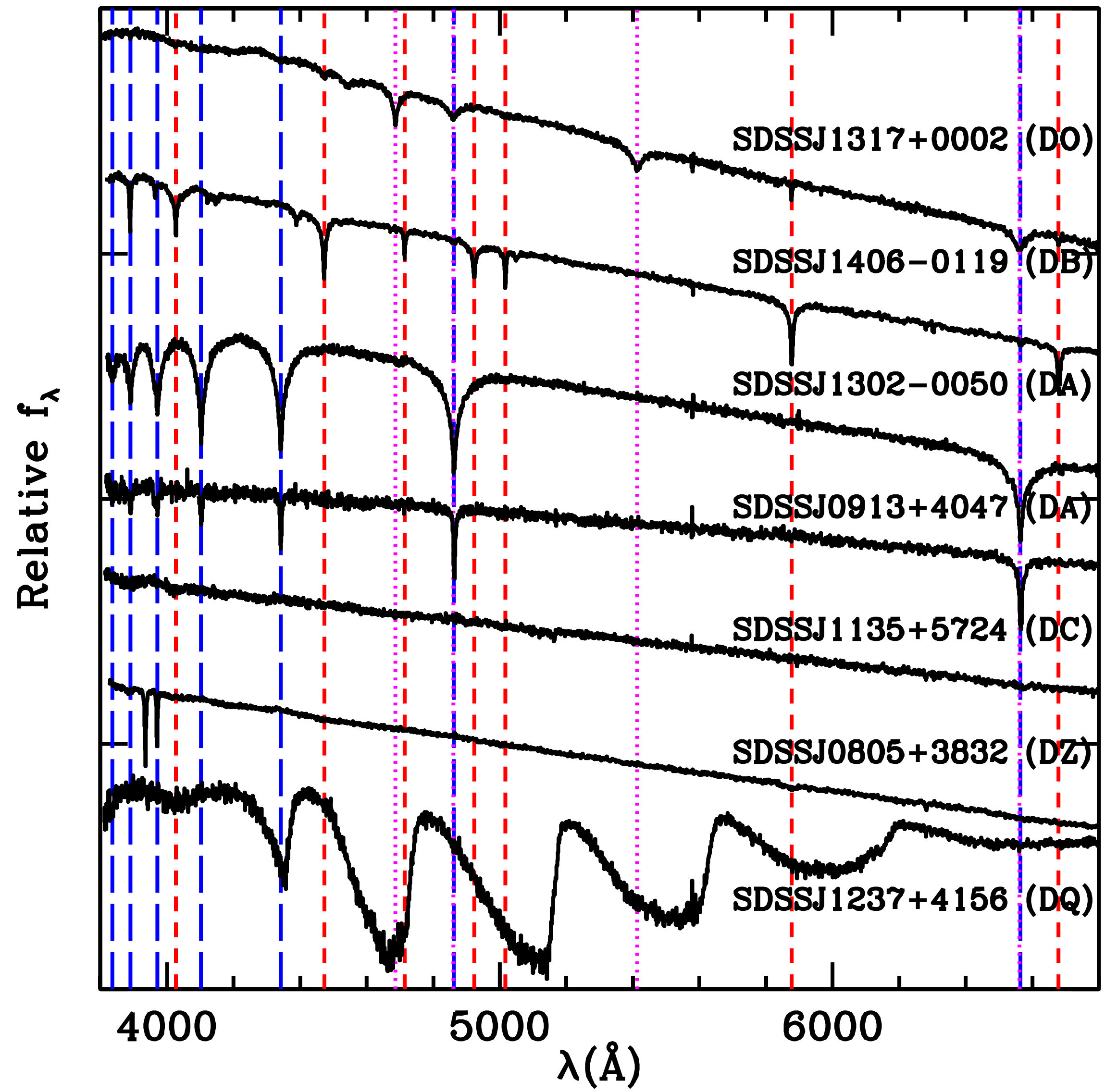
DO He II lines

DB He I lines

DC continuous spectrum

DZ metal lines (Ca, Na, Mg, Fe ...)

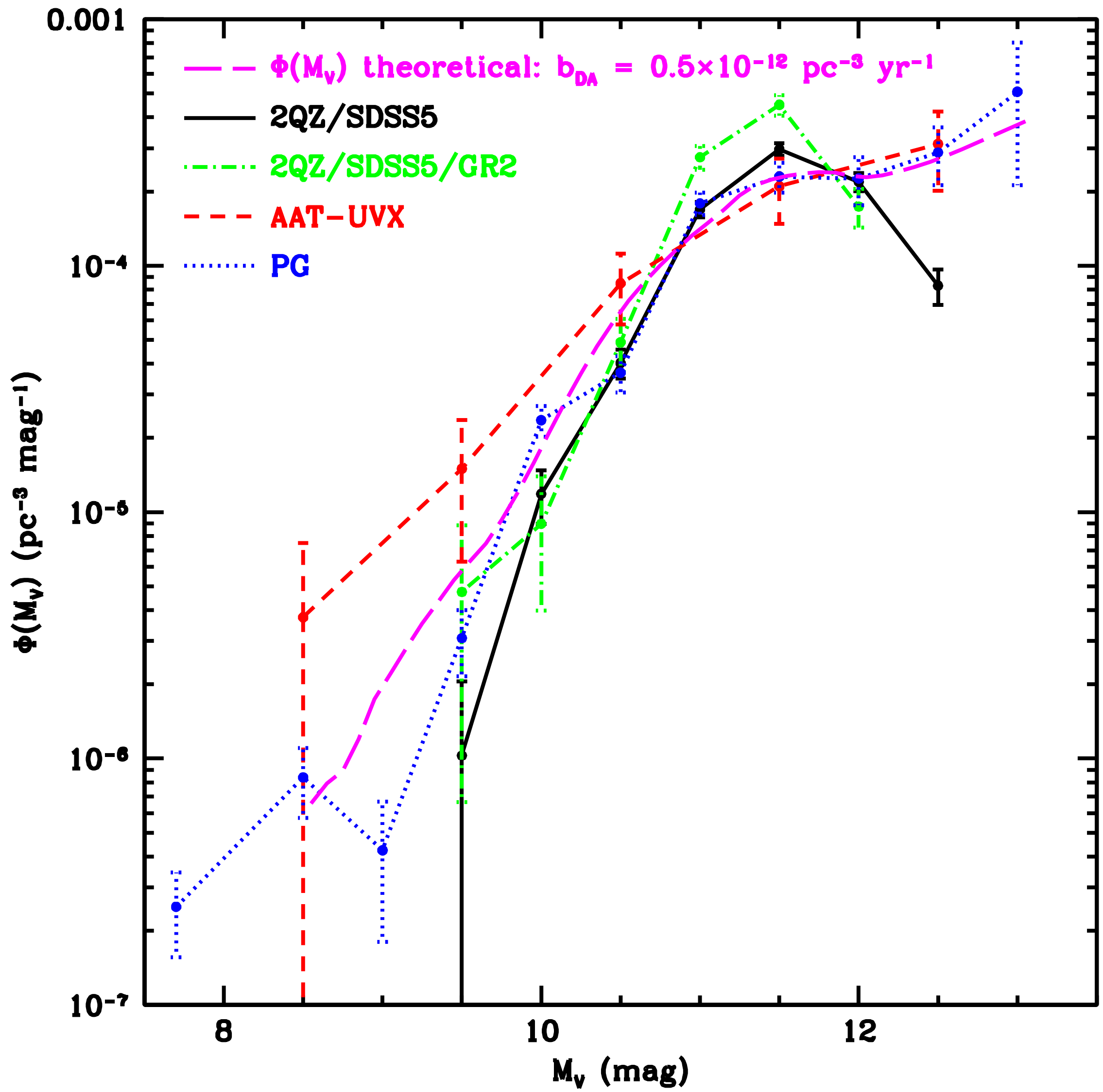
DQ carbon features



White dwarfs in the Galaxy

- white dwarfs help to determine the age of the Galactic disk
- the luminosity function (i.e. the number of stars per luminosity bin) can be used to constrain the Galactic evolutionary models

Kawka & Vennes (2007)



- the motion of stars within the Galaxy can be described using:

  U - toward the Galactic center

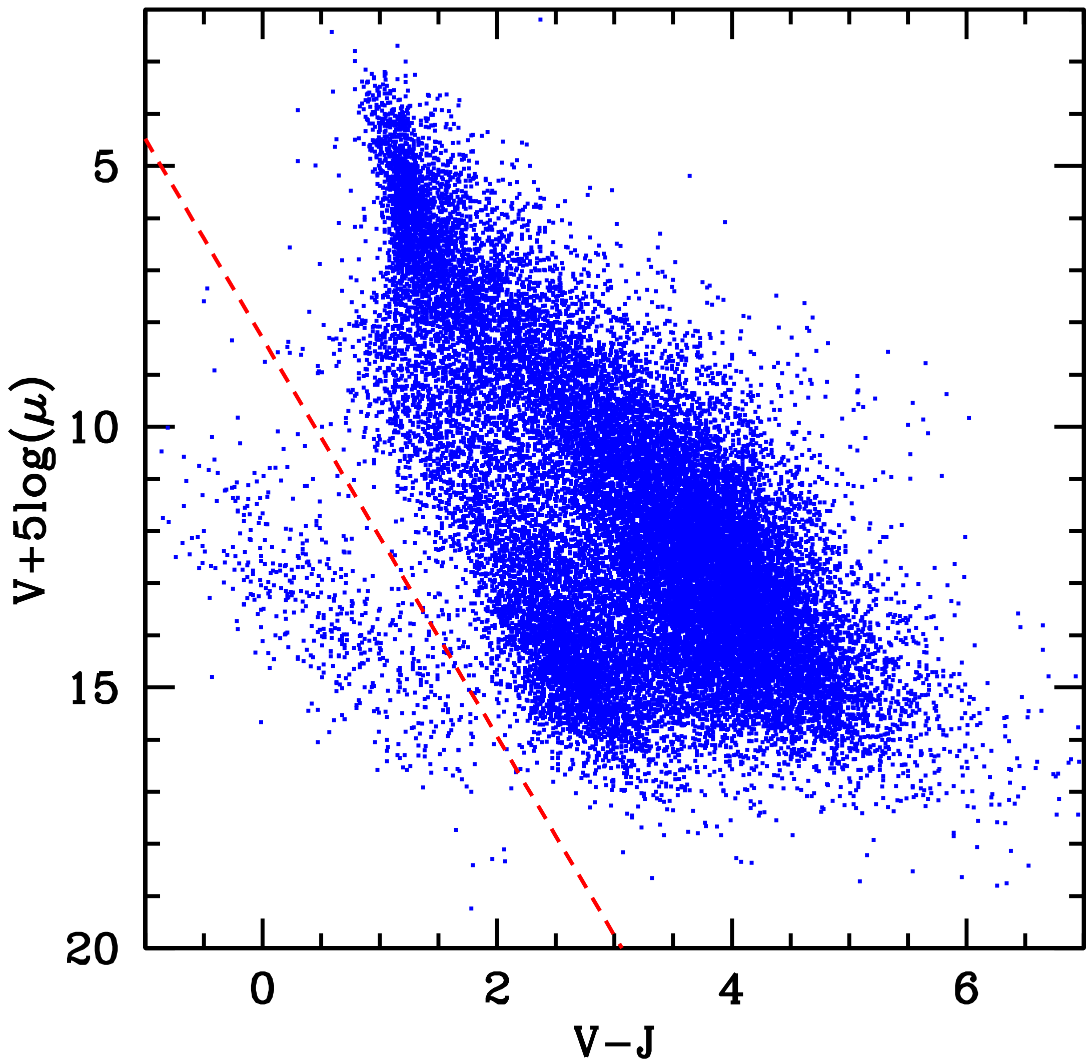
  V - in the direction of Galactic rotation

  W - toward the north Galactic pole

- kinematics of a sample of stars can be used to determine which group it belongs to:
  - thin disk – most of white dwarfs
  - thick disk – contribution to the local sample between 5% and 25%
  - halo – the oldest white dwarfs

The sample of white dwarfs

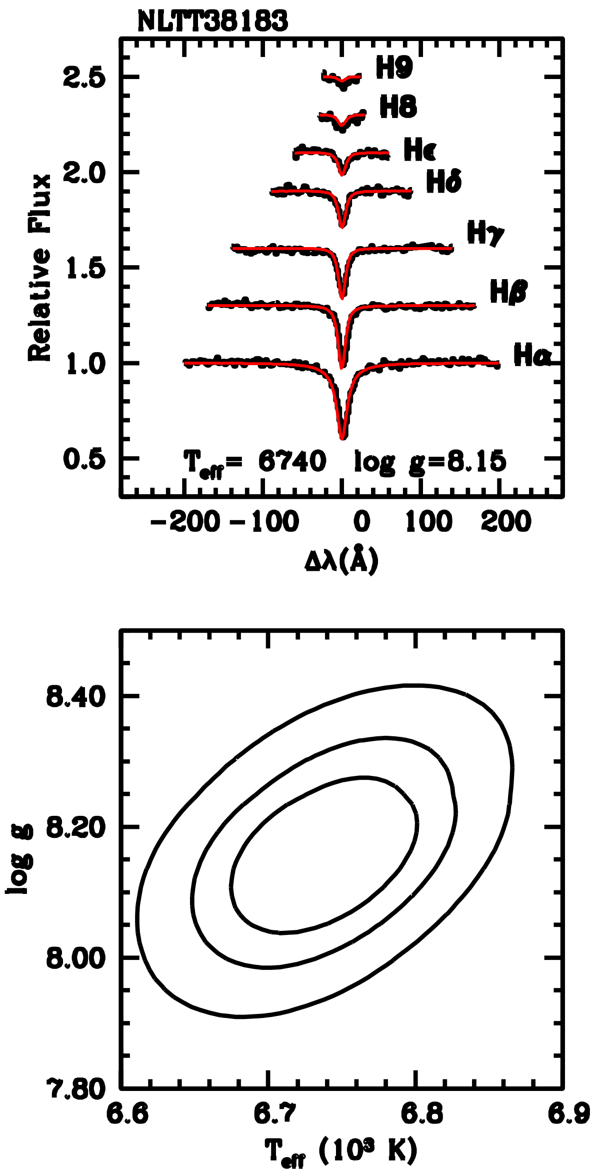
Salim & Gould (2002)



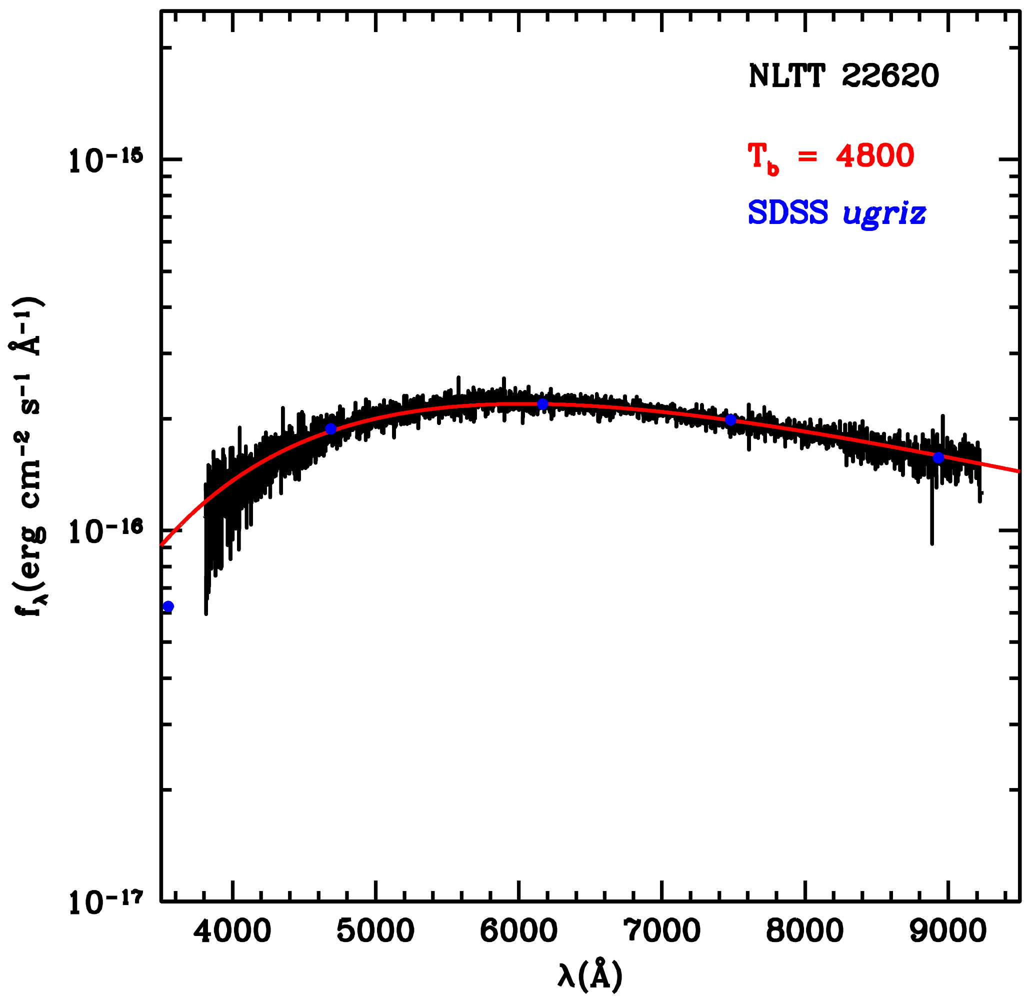
- Cerro Tololo Inter-American Observatory (CTIO)
- Sloan Digital Sky Survey (SDSS)
- sample of 90 white dwarfs, for 78 object were not known any physical properties
- another 120 objects were already examined by other authors

Analysis of spectra

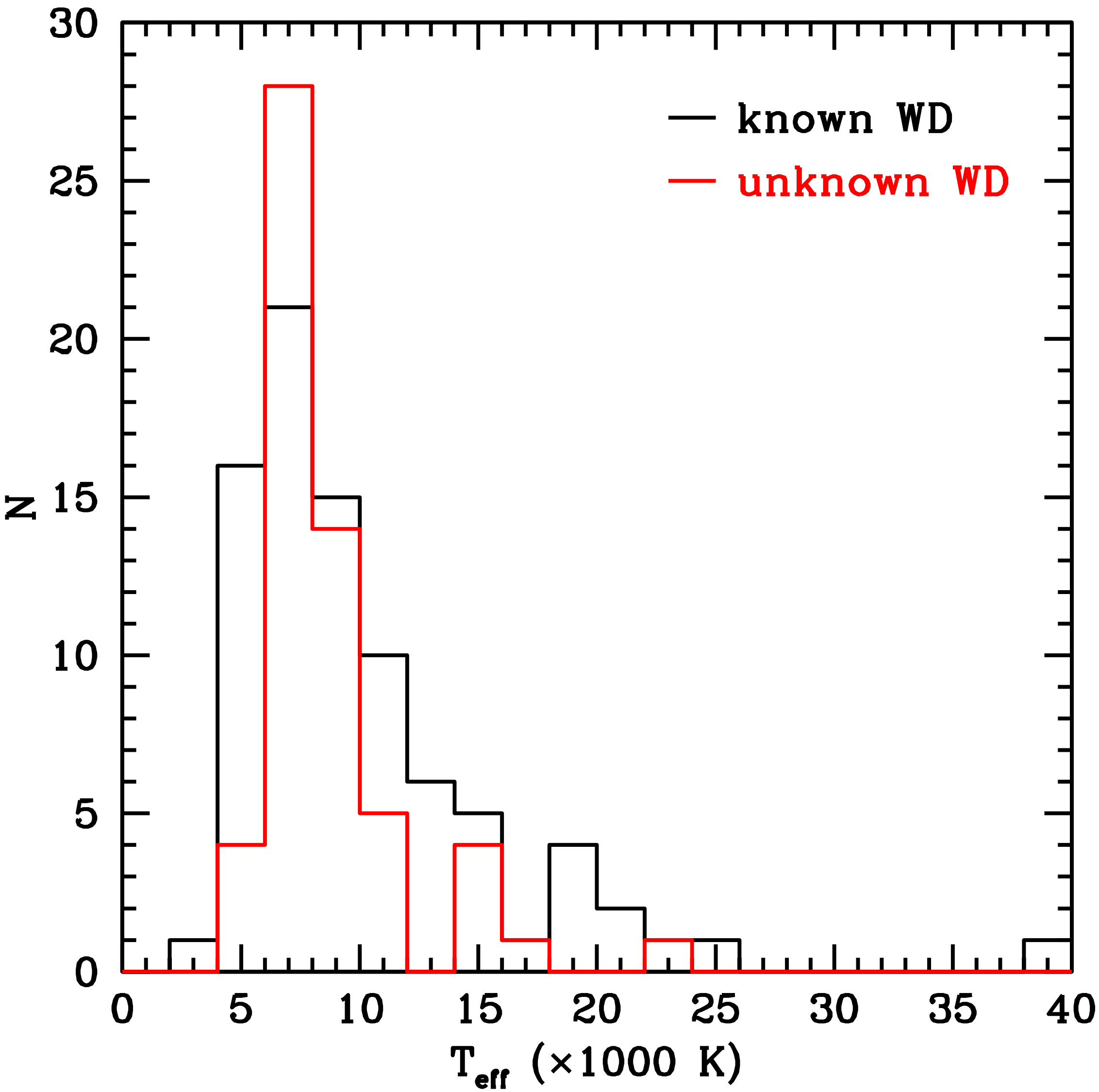
- **DA white dwarfs**
  - for fitting used program by S. Vennes and A. Kawka
  - Balmer lines Hα up to H9
  - used models:
    - pure hydrogen LTE plane-parallel models
    - T_{eff} = 4 500 K up to 100 000 K for log(g) = 7.0 up to 9.5
    - radiative and convective (included by apllying the Schwartzschild stability criterion and by using the mixing length formalism) energy transport
    - broadening mechanisms of spectral lines: linear Stark, Doppler, resonance, natural
  - used χ^2 minimization technique


NLTT38183
H9
H8
Hε
Hδ
Hγ
Hβ
Hα
Relative Flux
T_eff= 6740 log g=8.15
Δλ(Å)
NLTT06876
H9
H8
Hε
Hδ
Hγ
Hβ
Hα
Relative Flux
T_eff=23460 log g=7.71
Δλ(Å)
log g
T_eff (10³ K)
log g
T_eff (10³ K)

- **DC and DZ WDs**
  - spectra compared to the spectra of black body
  - relatively cool objects, over $\sim$ 10 000 K we need He models
  - possible to use also for DZs, because metal lines in their spectra are weak enough



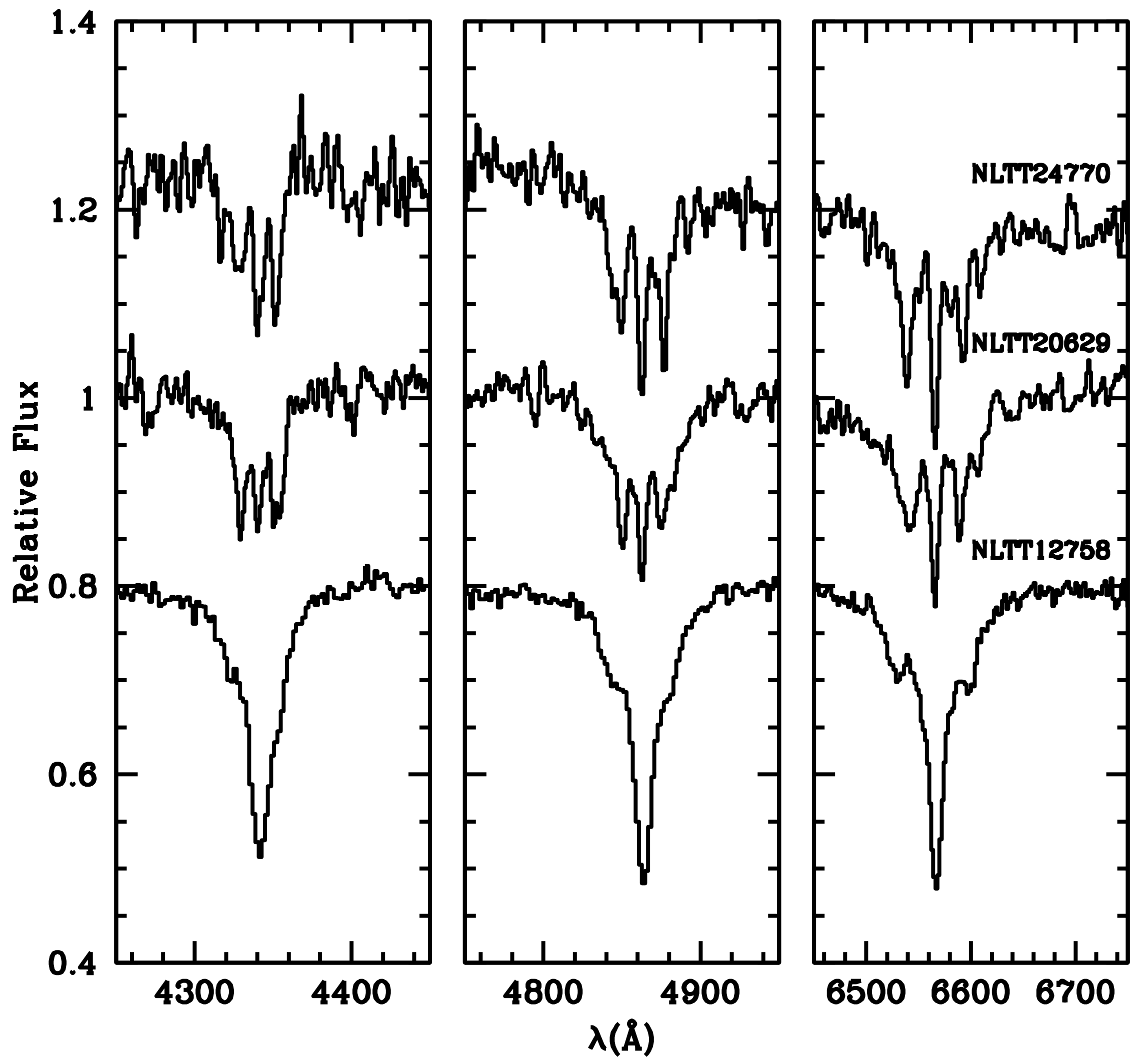
- **DQ white dwarfs**
  - for estimation of effective temperature used paper Dufour et al. (2005)
  - assumption of log(g) $\sim$ 8.0
  - temperature of white dwarf NLTT 27901 adopted from paper Koester $\&$ Knist (2006)
- **DB white dwarfs**
  - only two objects, both DBA white dwarfs
  - effective temperatures and surface gravities adopted from paper Voss et al. (2007)



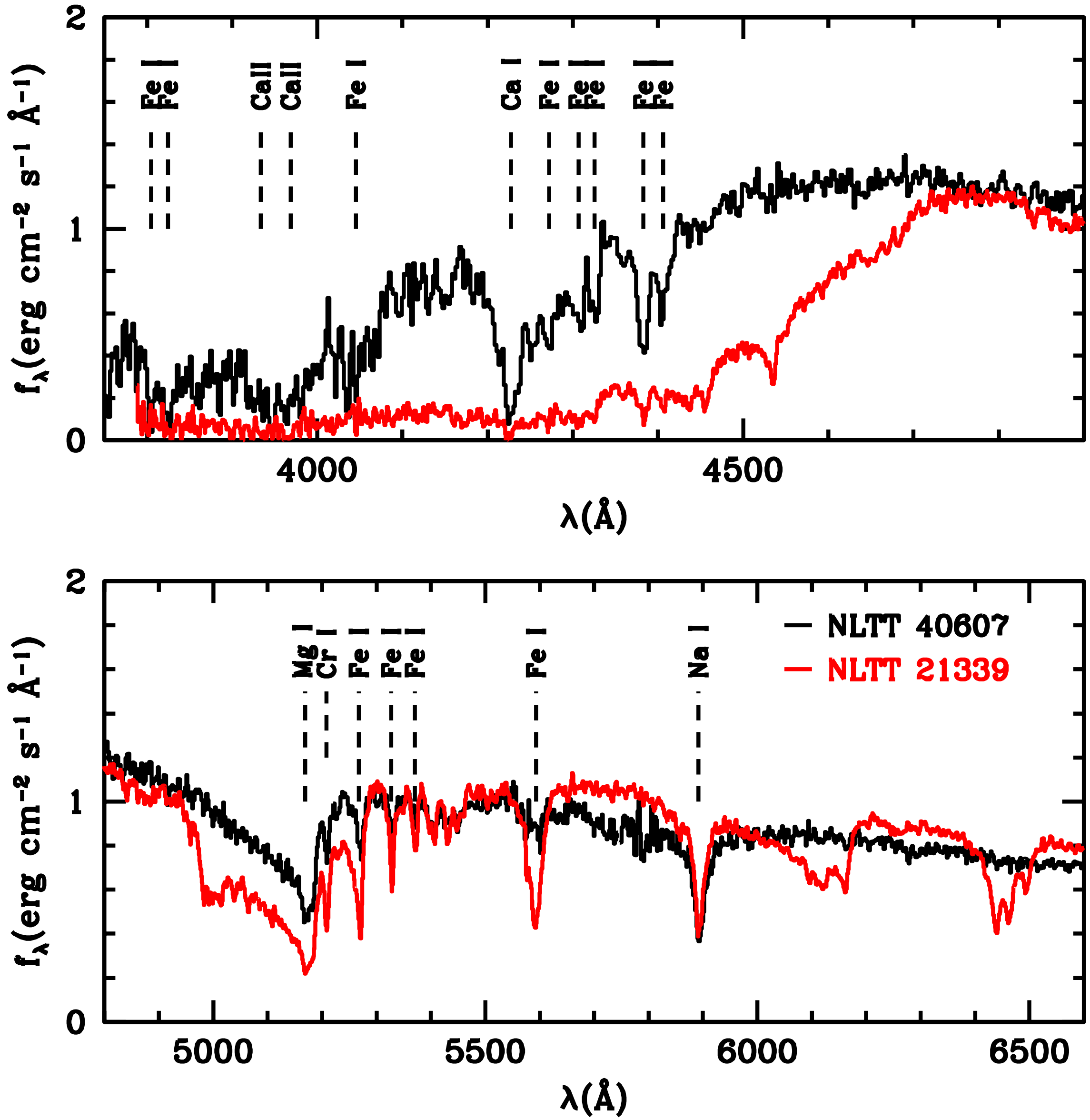
- average effective temperature in our sample 8 300 K, in all collection of white dwarfs 9 150 K
- DA white dwarfs 9 530 K, non-DA white dwarfs 7 260 K

Interesting white dwarfs

- three DAP objects
  - NLTT 20629 – T_{eff} = 6 550 K, B = 1.2 MG
  - NLTT 24770 – T_{eff} = 7 150 K, B = 1.3 MG
  - NLTT 12758 – T_{eff} = 7 450 K, B = 1.7 MG

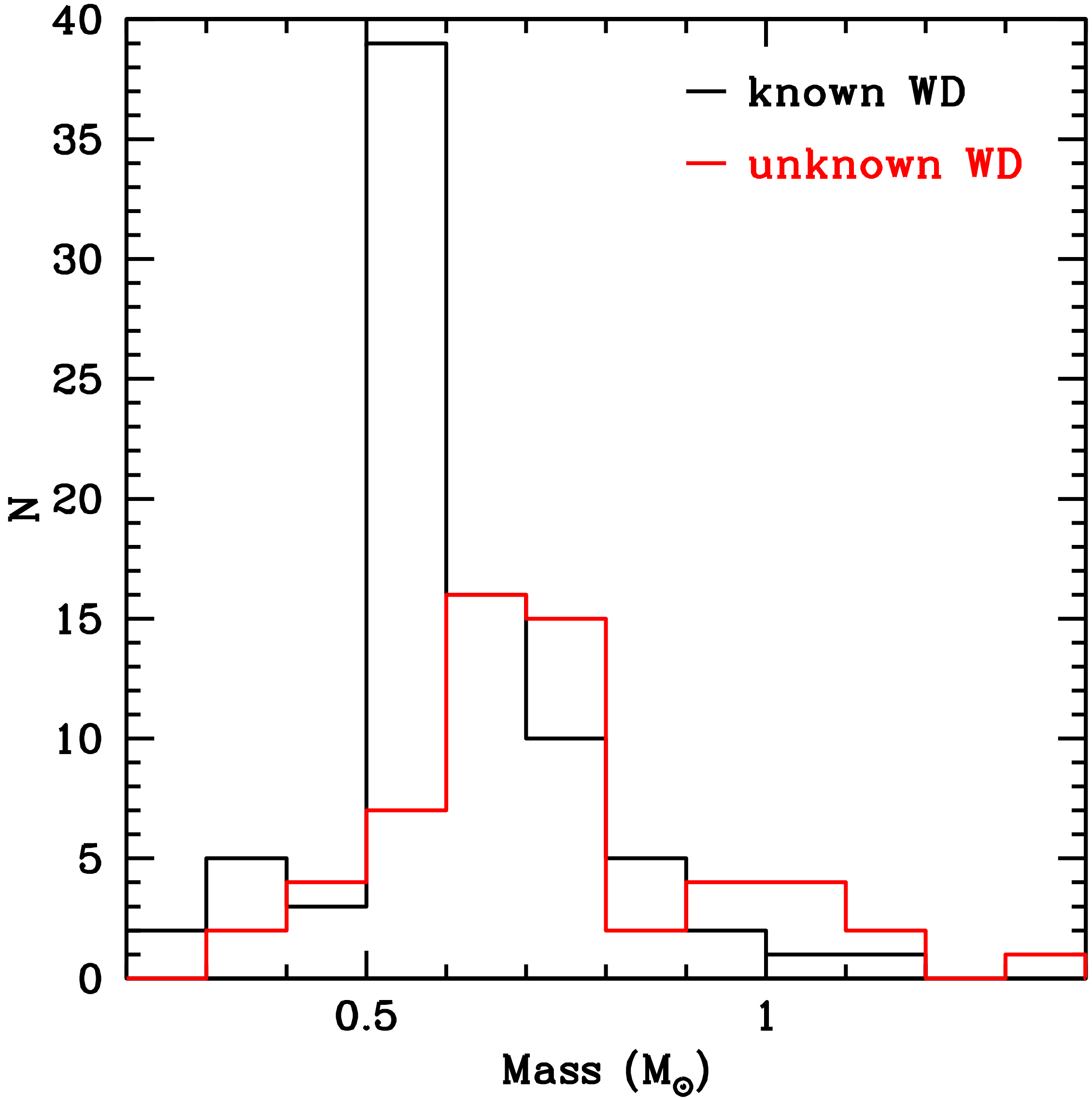


- NLTT 43827 – log(g) = 9.35, M = 1.31 $M_\odot$
- NLTT 33108 – ZZ Ceti star
- NLTT 5943 – hot DQA white dwarf
- NLTT 21339 – DZ with high abundance of heavy elements



Further properties of white dwarfs

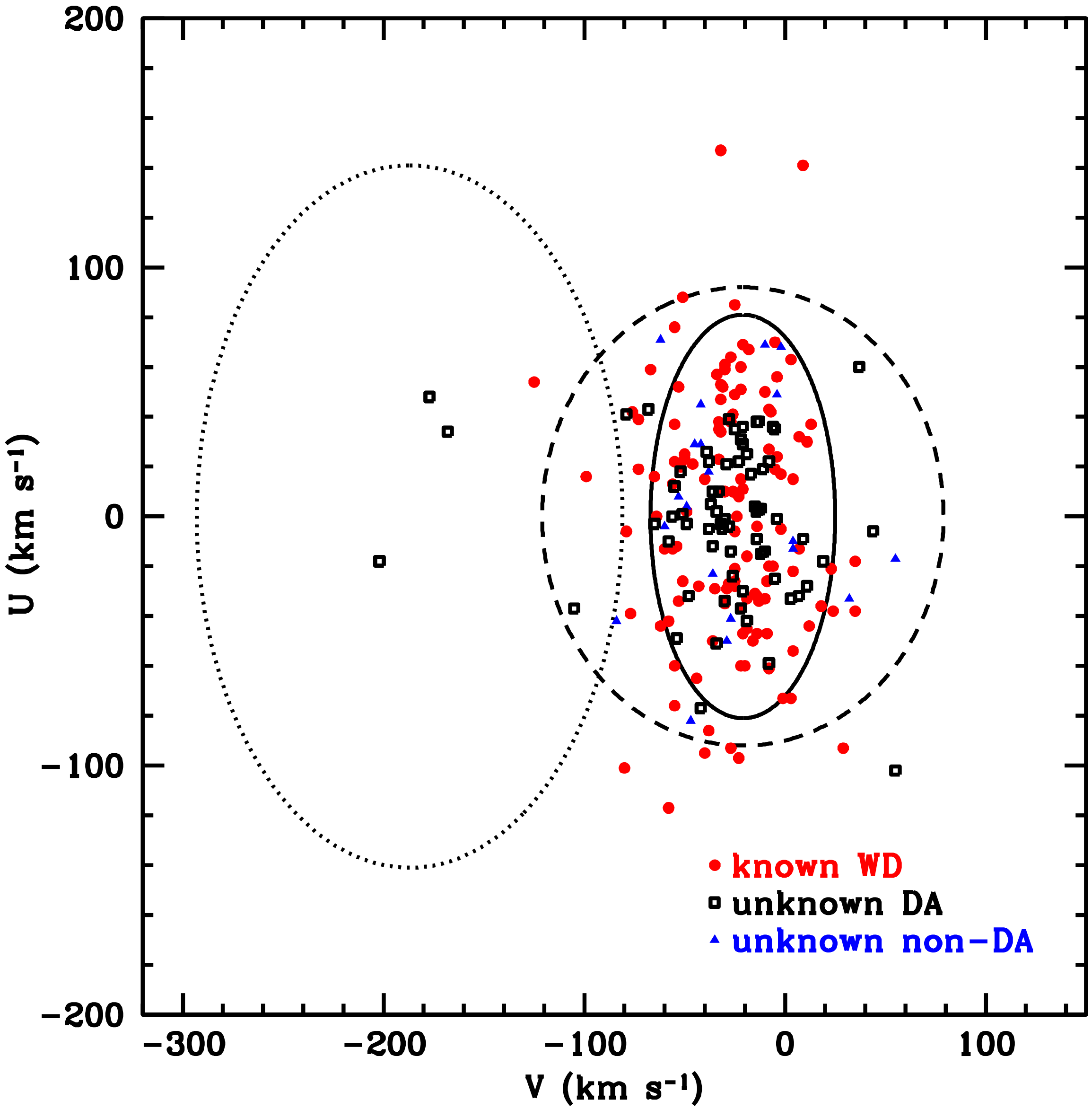
- mass and cooling age determined using interpolating program by A. Kawka (Althaus & Benvenuto, 1998)
- used models:
  - white dwarfs with CO core and H envelope (DA)
  - white dwarfs with CO core and without H envelope (non-DA)
  - 0.45 $M_\odot$ up to 1.2 $M_\odot$
  - $\frac{M_H}{M} = 10^{-4}$
  - solar metalicity
- absolute magnitude determined using already known effective temperature and mass
- distance gained from adaptation of Pogson equation



- average mass in our sample 0.73 $M_\odot$, in all collection of white dwarfs 0.67 $M_\odot$
- DA white dwarfs 0.67 $M_\odot$, non-DA 0.68 $M_\odot$
- the best agreement with average mass 0.665 $M_\odot$ from paper Holberg et al. (2008)

Kinematics

- program by S. Vennes (Johnson $\&$ Soderblom, 1987)
- data imput:
  - right ascension and declination to equinox 1950
  - proper motion μ and angle θ
  - distance
  - radial velocity
- output: velocity components U, V and W with regard to LSR



- 195 objects belong to the population of the thin disk
- 6 halo candidates, only NLTT 32057 (known) and NLTT 31473 (CTIO) cool enough

Main results

- analysis of 90 spectra of white dwarf selected from rNLTT catalog and determination of their effective temperature and surface gravity
- for 78 objects from this sample were not known any physical properties
- calculation of magnetic field for DAP white dwarfs
- temperature distribution of collection of 210 white dwarfs
- determination of mass, absolute magnitude, distance and cooling age for all 210 objects
- mass distribution, comparison with literature

- calculation of velocity components U, V and W with regard to LSR for all 210 objects
- estimation of fraction of white dwarfs in particular populations in Galaxy
- luminosity function for DA white dwarfs
- discussion of difficulties in determining age of the Galactic disk from our luminosity function
- discussion of fractions of particular spectral types of white dwarfs in our sample, comparison with literature
- contribution to the local sample of white dwarfs – 6 objects within 20 pc from the Sun

Further work

- to acquire spectra of larger sample of white dwarfs in the Solar neighborhood (e.g. ESO, Ondřejov)

- determine their atmospheric parameters
- already known data adopt from literature
- such a huge sample of objects could enable us:
    - to have better statistics of fractions of white dwarfs in particular populations in Galaxy
    - to plot luminosity function for higher magnuitudes
    - to determine age of the Galactic disk
- to dispose helium models for white dwarfs (the largest error in our work is in determination of effective temperature for non-DA white dwarfs)

- to analyze more interesting white dwarfs (e.g. magnetic field, abundance of heavy elements)
- to gain radial velocities (assumption $v_{rad} = 0 \longrightarrow$ underestimation of number of members of thick disk)
- to acquire trigonometric parallaxes to confirm distances of white dwarfs (astrometric satellite Gaia)

rNLTT Catalog

- Salim & Gould (2003)
- NLTT cross-correlated with 2MASS (Two Micron All Sky Survey) and USNO-A Catalogs
- 36 085 objects
- at bright magnitudes (V $\lesssim$ 11 mag) complete for $|\mathrm{b}| \gtrsim 15^{\circ}$
- coverage of sky 38%, $\delta >$ -33°
- absolute magnitudes in the range from 10 mag up to 17.5 mag
- errors: position – 130 mas, proper motion – 5.5 mas·yr^{-1}, V $-$ J color – 0.25 mag
- $\longrightarrow \sim$ 400 white dwarf candidates

LSPM Catalog

- Lépine $\&$ Shara (2005)
- search for high proper motion stars in the Digitized Sky Surveys using SUPERBLINK software, incorporated Tycho-2 Catalog and ASCC-2.5 (All-Sky Compiled Catalog of 2.5 million stars)
- northern stars with annual proper motions larger than 0.15"
- 61 977 objects
- complete for V < 19 mag stars at $|\mathrm{b}| \gtrsim 15^{\circ}$
- limiting magnitude V $=$ 21 mag
- errors: position – 100 mas, proper motion – 8 mas·yr^{-1}
- $\longrightarrow \sim$ 800 white dwarf candidates

non-DA white dwarfs

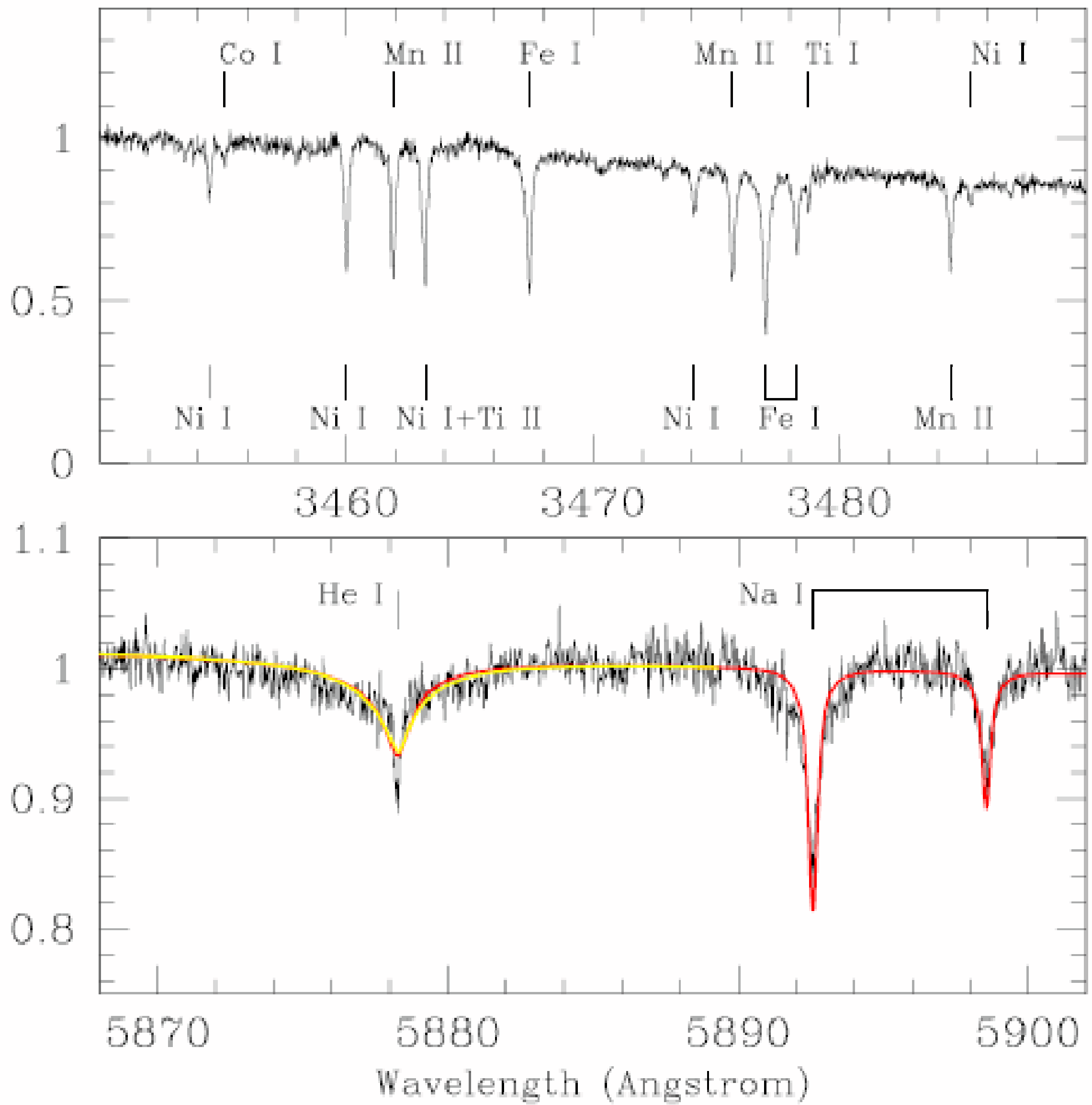
- $\sim$ 25% of white dwarfs have helium-dominated atmosphere
- are born with H-deficient atmospheres or processes such as diffusion, accretion, convection, radiation pressure and stellar winds compete with gravitational settling as they cool off
- DB gap (T_{eff} between 45 000 K and 30 000 K) – as DOs cool residual amount of hydrogen accumulates to the surface
- pure helium LTE plane-parallel models
- add opacity in models (for the coolest atmospheres dominated by He^{-} free-free absorption and Rayleigh scattering by neutral He)

Cool white dwarfs

- for white dwarfs with $T_{eff} \lesssim 25\,000$ K, elements heavier than H and He start to sink down to the centre, under $\sim 11\,000$ K becomes invisible also He
- explanation of presence of heavy elements in white dwarf atmospheres:
  - fallback of dusty debris following a merger event
  - accreation of interstellar matter
  - accretion of material from ancient planetary systems
- if there is present helium in white dwarf atmosphere, it can cause significant broadening of Balmer lines, which could be considered as high value of surface gravity

GD 362 (WD 1729+371)

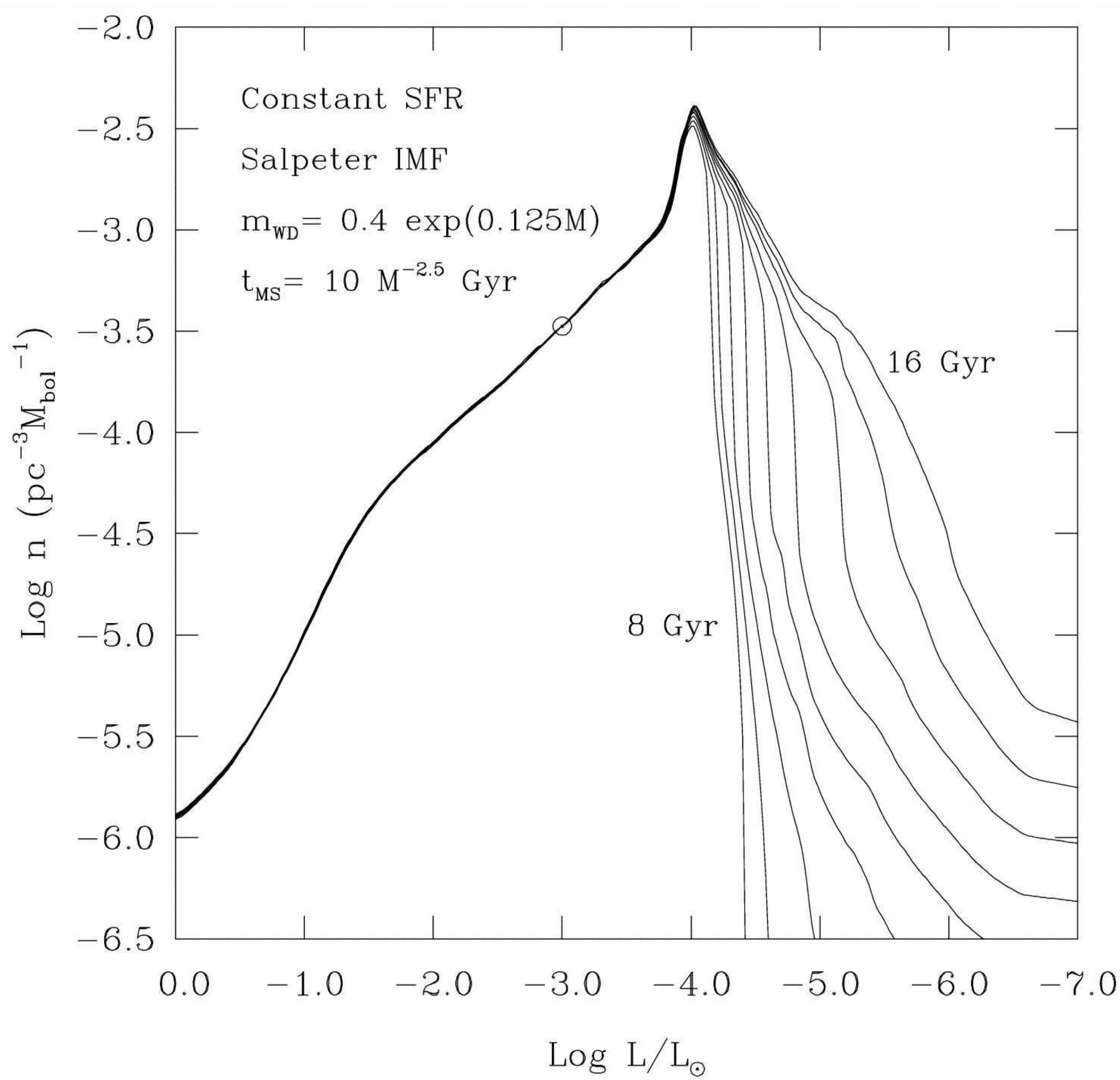
- Gianninas et al. (2004), Kawka et al. (2005) – most massive (1.2 $M_\odot$) DAZ (Ca I, Ca II, Mg I and Fe I) white dwarf ever found, T_{eff} = 9 740 K, log(g) = 9.1, $d \simeq$ 24 pc
- Kilic et al. (2005), Becklin et al. (2005) – IR excess $\rightarrow$ circumstellar disk
- García-Berro et al. (2007) – proposed explanation by merger of two white dwarfs
- Zuckerman et al. (2007) – presence of significant amount of He (log[He/H] = 1.14), T_{eff} = 10 540 K, log(g) = 8.24, $d \simeq$ 50 pc
- Kilic et al. (2008) – π = 19.9 $\pm$ 1.3 mas $\rightarrow$ d = 50.3 $\pm$ 3.3 pc, confirmation of He dominated atmosphere, $M \approx$ 0.71 $M_\odot$, $R \approx$ 0.0106 $R_\odot$



Zuckerman et al. (2007)

Luminosity function for DAs

- informs about star formation history and the local mass density in the galactic disk
- to built theoretical white dwarf luminosity function we must consider:
  - initial mass function ($\phi(M) = \left(\frac{M}{M_\odot}\right)^{-2.35}$, Salpeter, 1955)
  - star formation rate ($0.5 - 1.0 \cdot 10^{-12}$pc^{-3} $\cdot$ yr^{-1})
  - pre-white dwarf lifetime ($\tau_{\text{MS}} = 10\left(\frac{M}{M_\odot}\right)^{-2.5}$ Gyrs)
  - initial-to-final mass relationship
  - white dwarf cooling age

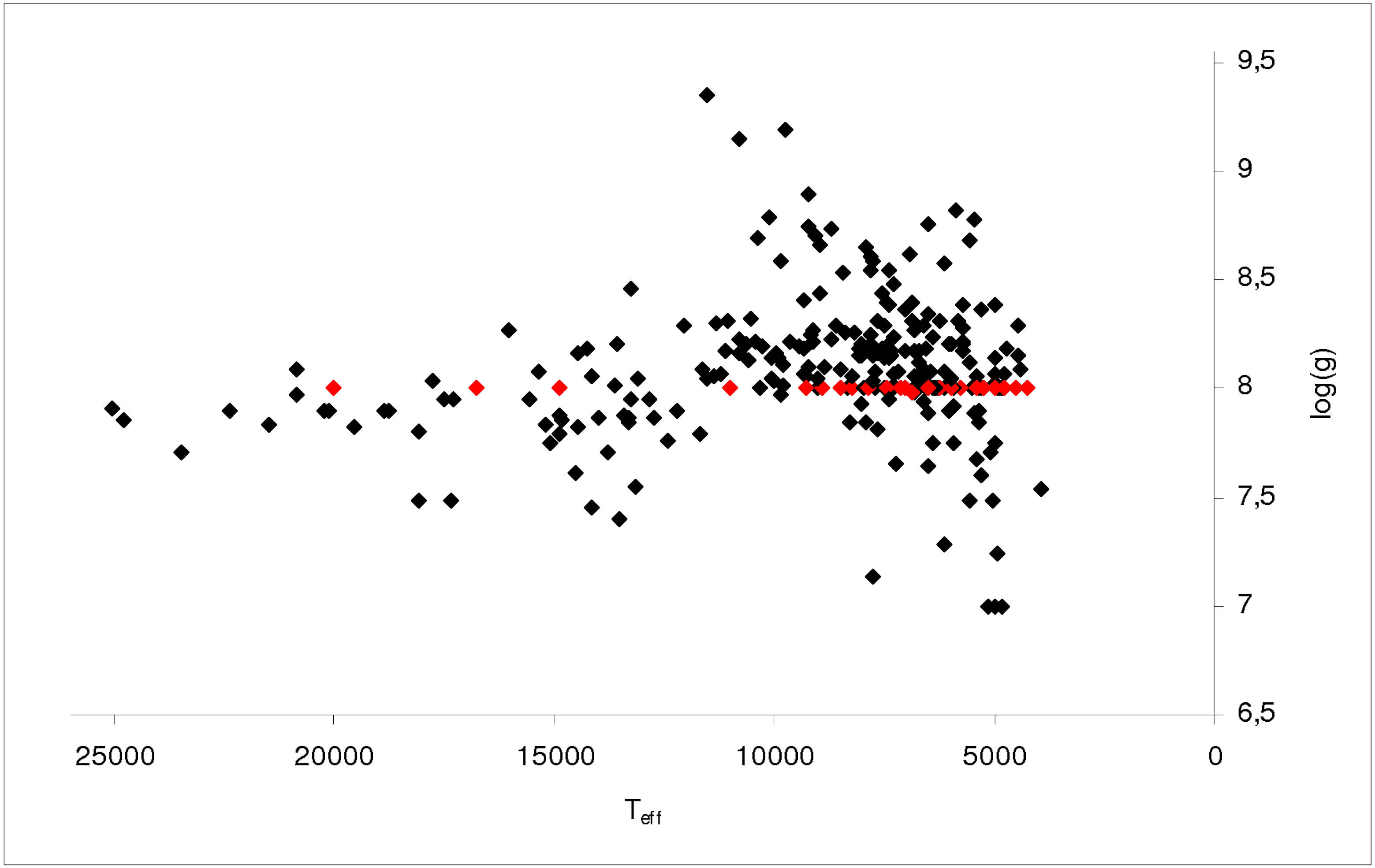


Fontaine, Brassard & Bergeron (2001)

- luminosity function could be built on the basis of absolute magnitude limit or volume limit
- Green (1980): set limitting magnitude, let V_m be volume defined by the maximum distance at which given object will still appear in the sample, define $\mathrm{d}V^{'} = \exp\left(-z/z_0\right)\mathrm{d}V$, where z_0 is the scale heigh $\rightarrow$ each star contribute to the local space density as $1/V_m^{'}$
- Galactic disk scale height of the white dwarf population ranges from $\sim$ 220 pc up to 300 pc
- if we have a complete sample of white dwarfs up to 20 pc from the Sun, we would be able to construct volume-limitted luminosity function

First results

- 417 objects selected from rNLTT catalog
- apparent magnitudes in the range from 12.06 mag up to 18.72 mag
- spectral types: 56% DA, 12% DC, 4% DQ, 3% DB, 3% DZ and 22% unknown (Kawka $\&$ Vennes (2006): 67% DA, 13% DC, 8% DQ, 7% DB, 5% DZ)
- effective temperature: arithmetic average 9163 K, median 7750 K, mode 5500 K, the highest value T_{eff} = 39910 $\pm$ 200 K for NLTT 32398, the lowest value T_{eff} = 3950 $\pm$ 70 K for NLTT 32057
- logarithm of surface gravity: arithmetic average 8.08, median 8.05, mode 8.0


9,5
9
8,5
8
7,5
7
6,5
log(g)
25000
20000
15000
10000
5000
0
T_eff

- mass: arithmetic average 0.64 $M_\odot$, median 0.61 $M_\odot$, mode 0.58 $M_\odot$, the highest value 1.31 $\pm$ 0.01 $M_\odot$ for NLTT 43827, the lowest value 0.18 $M_\odot$ for NLTT 53996
- 22% objects have measured parallax

References

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