Search for the coolest white dwarfs in the Galaxy

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- **Summary**

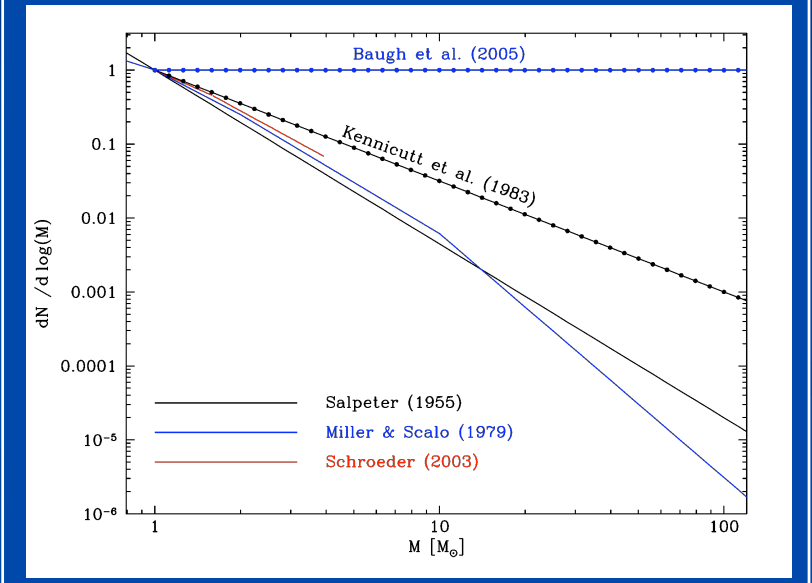
Motivation

Initial Mass function

- Distribution of stellar masses at birth
- fundamental property that quantifies the efficiency of the conversion of gas into stars in galaxies

- determination of many physical quantities of stellar populations and galaxies

- Observations of high-redshift galaxies provide a direct view of the earliest phase of star formation in the Universe, but an assumption of the IMF is necessary



Different IMFs

A direct test is possible locally in our Milky Way by studying the relic population (halo + thick disc WDs), which were formed at the same age of the Universe as the starbursts observed in high-redshift galaxies

WD luminosity function

- Several thin disc WD luminosity functions have been obtained so far

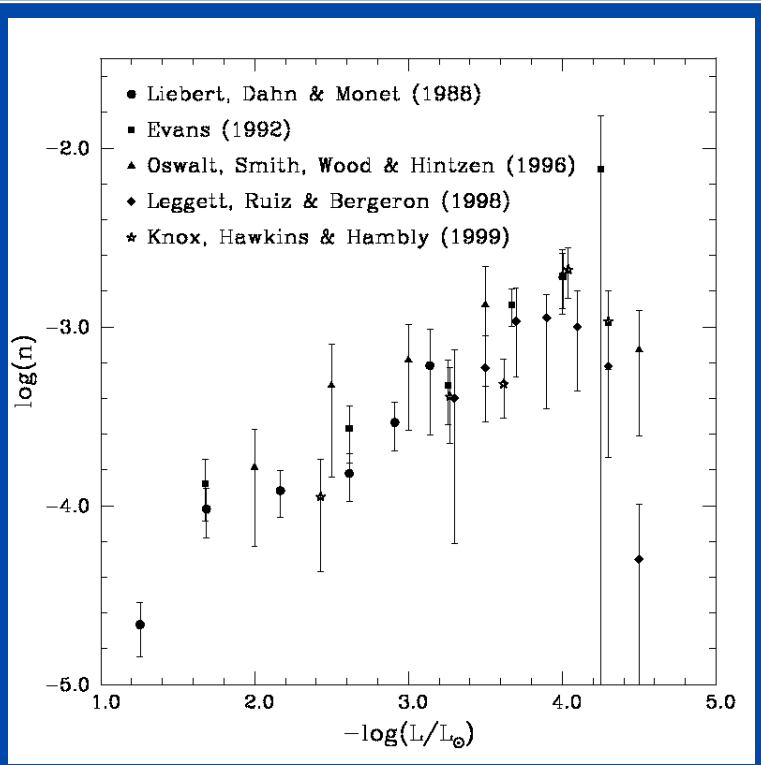
- convolution of IMF, star formation history, initial-final mass relationship and further complications, and are almost impossible to invert

- Thick disc and halo luminosity functions:

- were formed over a short period of time in the early days of our Galaxy

Interpretation much more straightforward

But cooler objects, more difficult to detect!



Thin disc WD luminosity functions

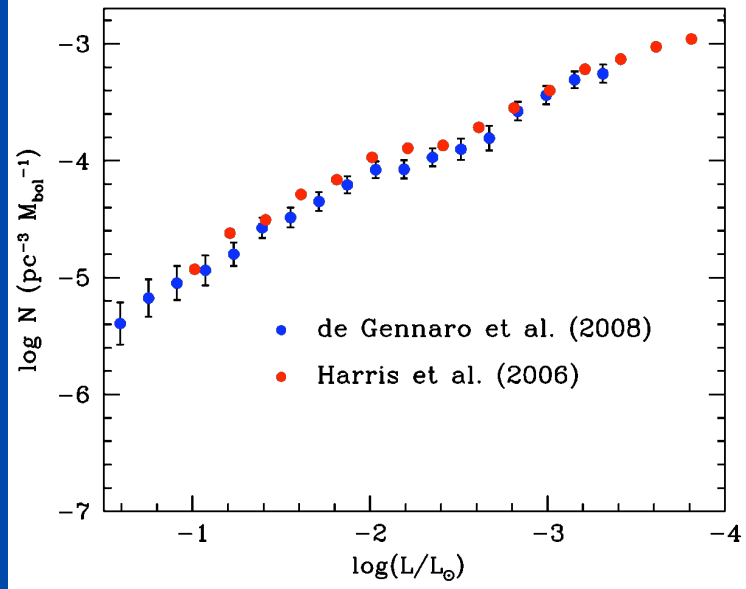
Current observational data

- SDSS is too shallow (g' r' ~22)

Harris et al. (2006), pop. I WD luminosity function comprising 6,000 WDs from SDSS:

only 35 cool WDs with abs mag > 15

We are interested in pop. II WDs, since they evolved from the most massive progenitor stars and are the oldest ones



SDSS WD luminosity function

We need deeper observations for that!!

WTS (WFCAM Transit Survey)

- **WFCAM at UKIRT telescope (Mauna Kea) + zyJHK filters**

main aim: detection of planetary companions to low mass, red main sequence stars for the light modulation caused by transits

Take over the time span of five years many repeat observations in NIR bands

6 sq degrees of total sky coverage

25 h in J band, reaching a depth of J = 23-24 mag (S/N=5) by co-adding observations

Proper motion: stacked WTS observations from different epochs (1-2 mas/yr accuracy)

50% of the WTS observations are completed and reduced so far

- Optical broadband photometry (SDSS g',r',i') obtaining depth of 25 mag (S/N=5)
  - 3.5m telescope + LAICA at CAHA (10 nights awarded)
  - INT + WFC at la Palma (6 nights awarded)

WTS fields

- Coordinates of the fields

Field	RA	DEC	l	b
03	03:39:01	+39:13:15	155	-13
07	07:04:34	12:56:00	203	9
17	17:14:00	+03:44:00	25	23
19	19:34:04	+36:29:36	70	8

- Fields chosen taking into account:

  - Avoid zenith distances < 5 degrees. Fields with DEC >>-20 and -30>>-45
  - |b|>10 to avoid contamination by reddened stars and giants
  - Spread in RA, 4 regions towards the Kuiper belt

Simulations

- **Napiwotzki (2008)** constructed a model of the Galactic WD population:

- based on the model of Galactic structure by Robin et al. (2003)
- Salpeter IMF
- WD cooling sequences from Blöcker (1995)
- WD progenitor lifetime, stellar tracks of Girardi et al. (2000), Padova Group
- Initial-final mass relationship of Weidemann (2000)
- population identification based on the results of the kinematic study of Pauli et al. (2006)
- calibrated with the local sample (Holberg et al. 2008)
- checked against the proper motion selected sample of cool WDs by Oppenheimer et al. (2001)

WD population in the WTS fields

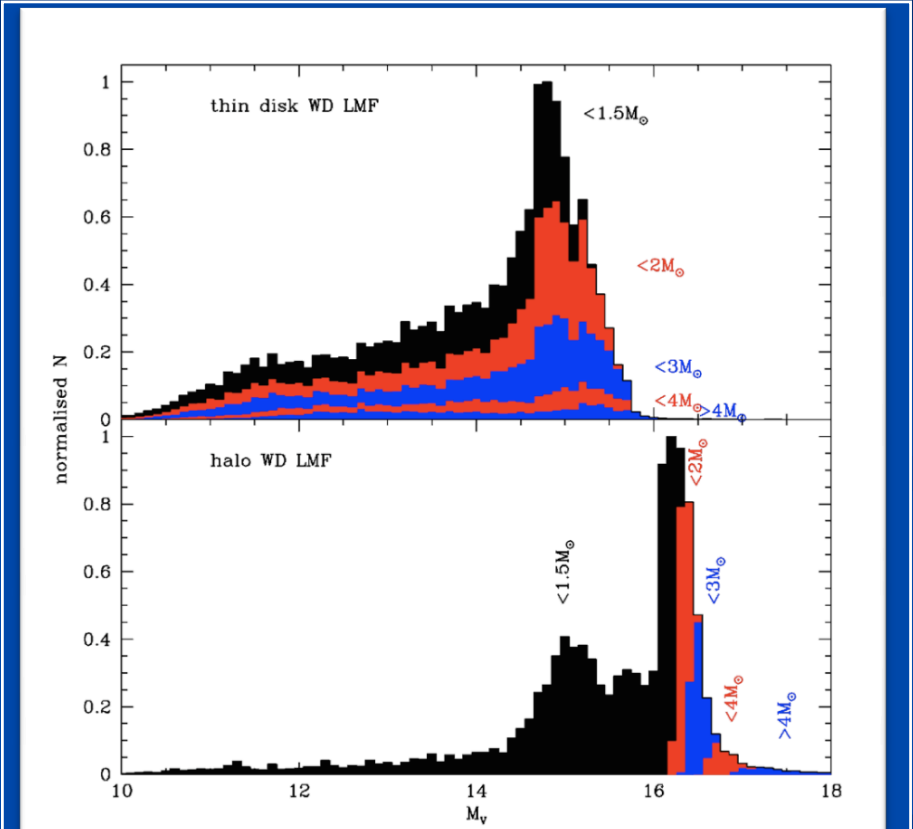
- **Napiwotzki (2008)**

- more than 1,500 WDs with μ>10mas/yr will be detected in the WTS fields (standard IMF)

- 100 cool WDs with Mv>15 mag (T_{eff} < 5,000 K) most of them thick disc and halo members

IMF	$N(M_{prog})>1.5M_{\odot}$	$N(M_{prog})>2.0M_{\odot}$	$N(M_{prog})>4.0M_{\odot}$
Salpeter	27	11	1
Baugh	135	94	26
Kennicutt	49	26	2

As expected, the predicted number of WDs with massive progenitors is much higher when Baugh IMF is adopted



Simulated WD luminosity function

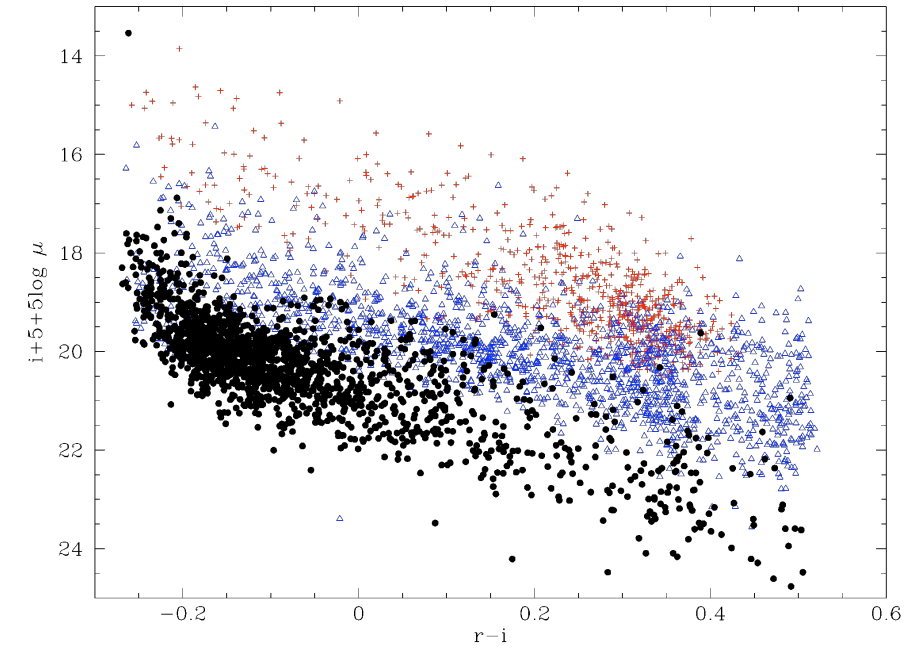
Reduced proper motion diagram

Combination of colours + pm

$$H_i = i + 5 \log \mu + 5$$

We have checked on the simulations that there is a good distinction of all three populations of WDs redder than r-i=0

- \+ thin disc
- Δ thick disc
- • halo



rpm diagram for a simulated sample of WDs brighter than 25 and with b~10 and μ>10 mas/yr

Cool WDs

Some have been detected (Harris et al. 2008, Kilic et al. 2010)

- **H-rich WDs**: show flux depression in the IR due to H molecule absorption

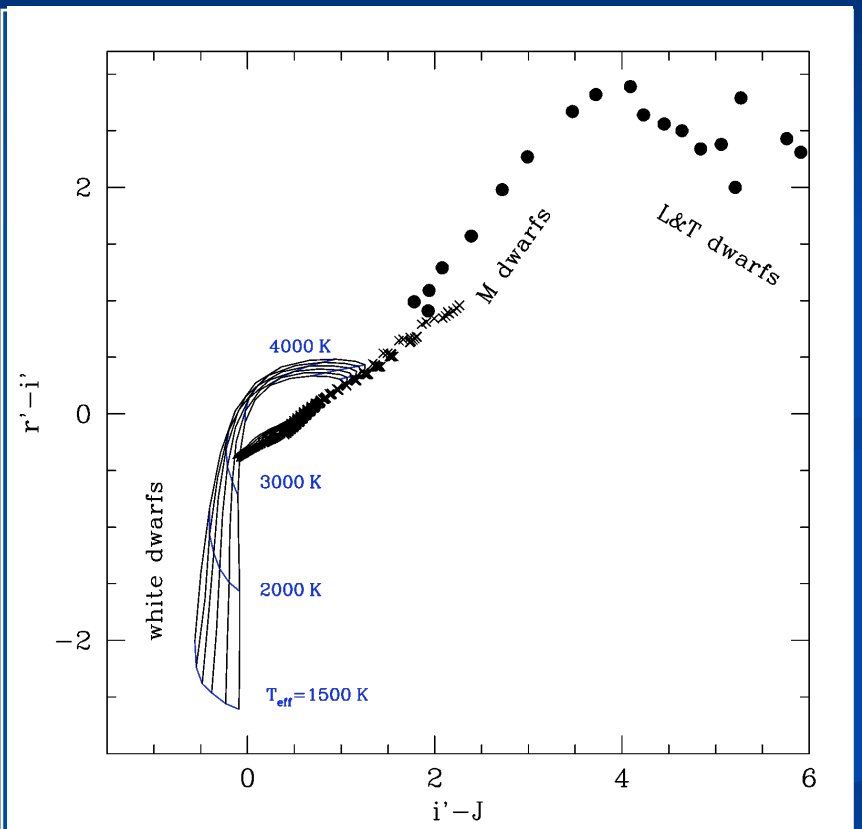
Some of these ultra-cool WDs are low-mass products of binary evolution, thus not representative for the oldest WDs (log g<7.5)

Old massive WDs (log g = 8.5-9.0)

- **He-rich WDs**: become very red with T_{eff}

IR observations better to study them

Cool WDs have SEDs very different from other types of cool objects



Colour-colour diagram r-i vs i-J

(Holberg & Bergeron 2006)

Colour-colour diagrams

Good T_{eff}/log g sensitivity for the cool, old WDs produced by massive progenitors (T_{eff} < 4000K)

Good accuracy in photometry:

T_{eff} + log g —(cooling tracks)→ M_{wd} —(IFMR)→ M_{prog}

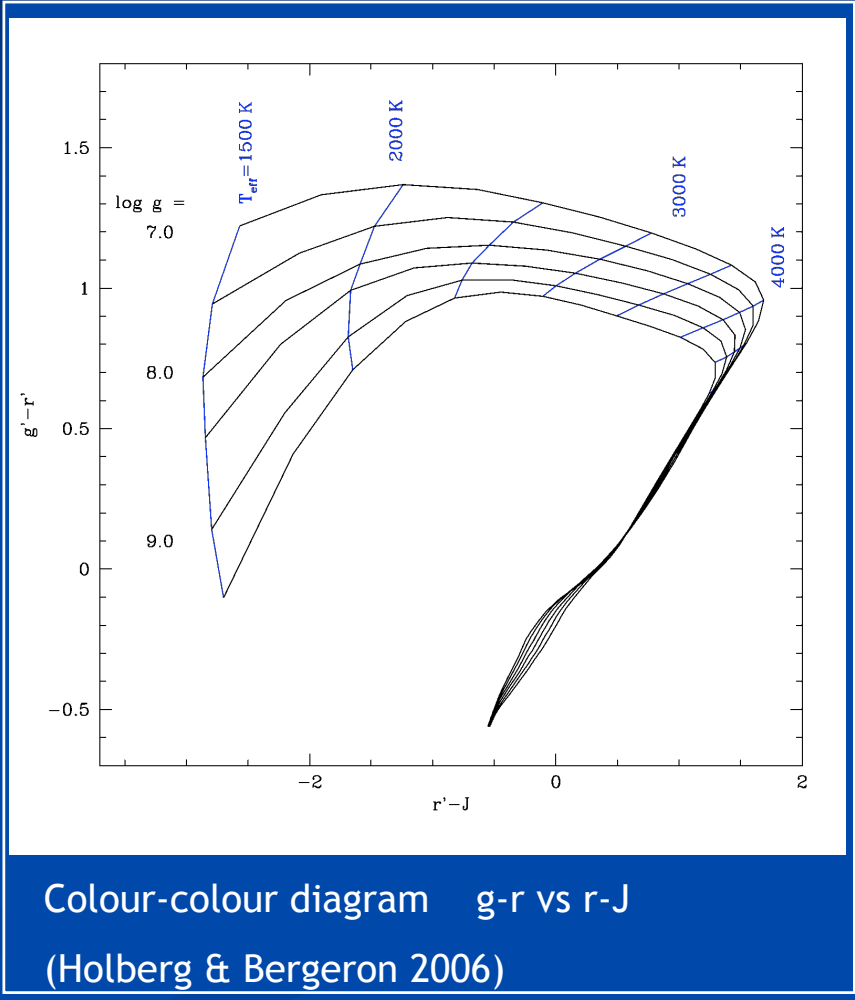
(100-200K, 0.2-0.3 dex)

For hotter WDs or when log g are not accurate:

T_{eff} —(cooling tracks)→ t_{cool} —(stellar tracks)→ t_{prog} → M_{prog}

t_{prog}= Halo age – t_{cool}

(this method can be used to improve the IFMR as well)

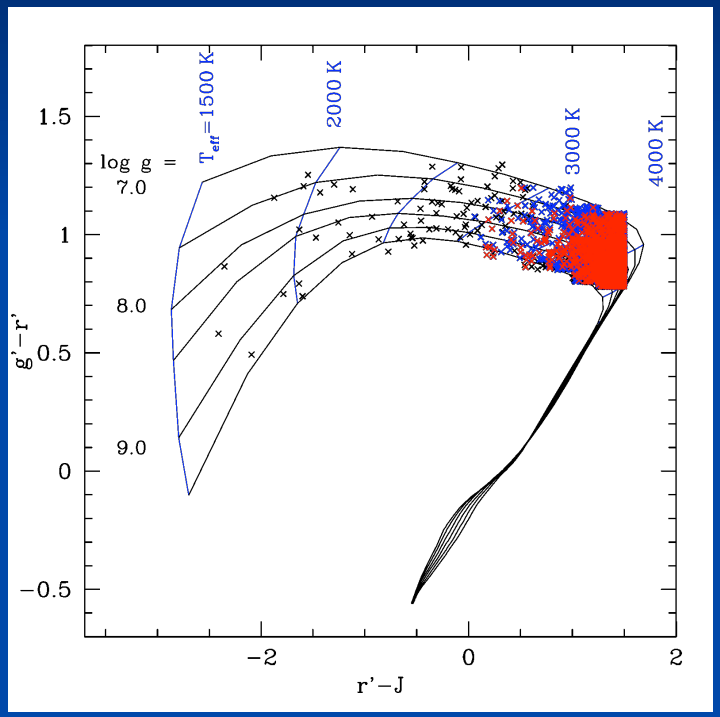


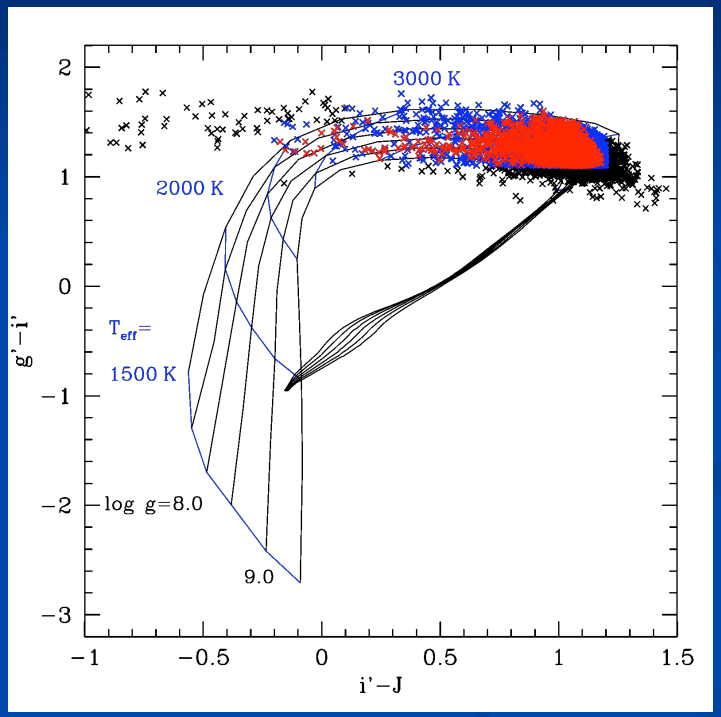
Colour-colour diagram g-r vs r-J

(Holberg & Bergeron 2006)

Preliminary Results

19h field: IR observations complete + 50% optical observations





Color cuts used: 0.2 < g-r< 1.3 -0.6 < r-i < 0.6 g-i <1.8 J >14

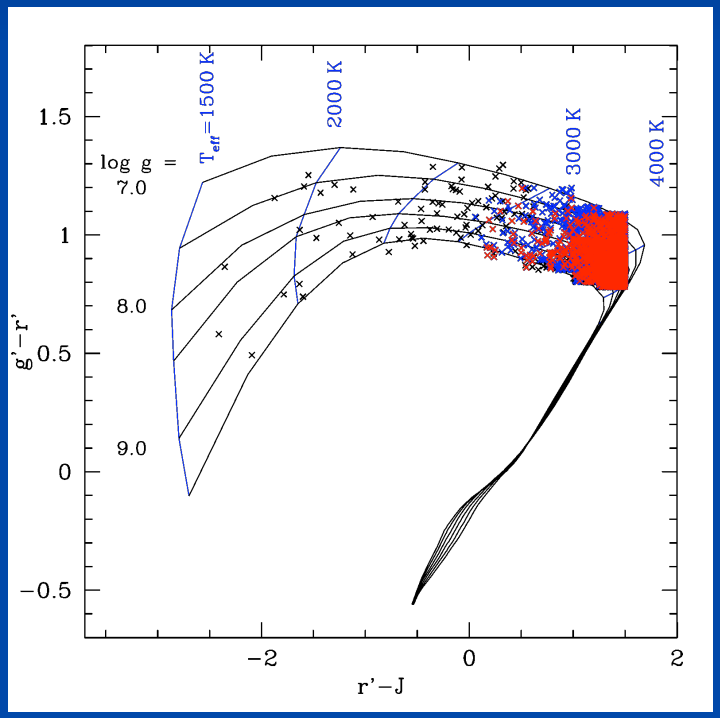
Work in progress: - proper motion calculation, will help to get rid of possible contamination (extragalactic objects)

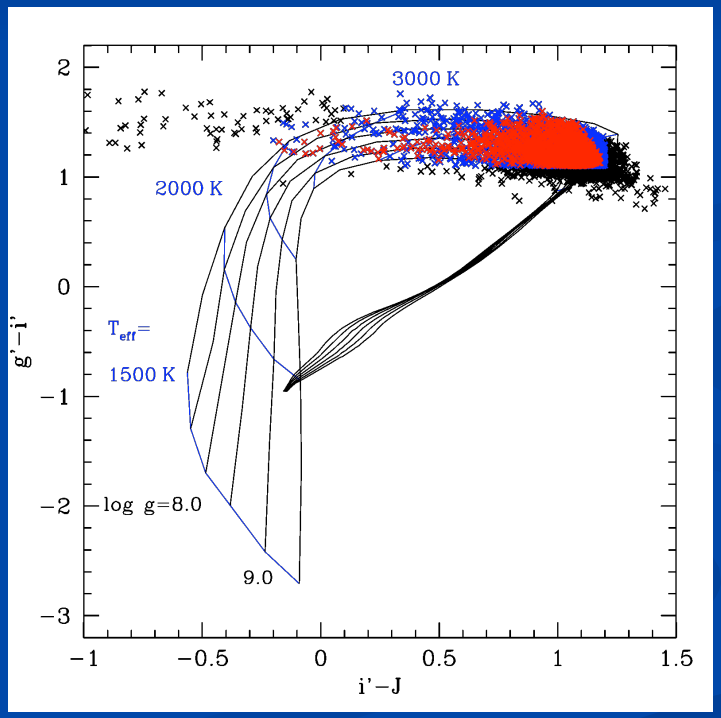
- improve accuracy of J mag

Atmospheric parameters

Fit of griJ to synthetic magnitudes (Holberg & Bergeron 2006) based on Levenberg-Marquardt method to minimize χ^2

For the T_{eff} < 4,000 K, free parameters: T_{eff}, log g and $(R/d)^2$





x T_{eff} and log g

χ^2_r<5

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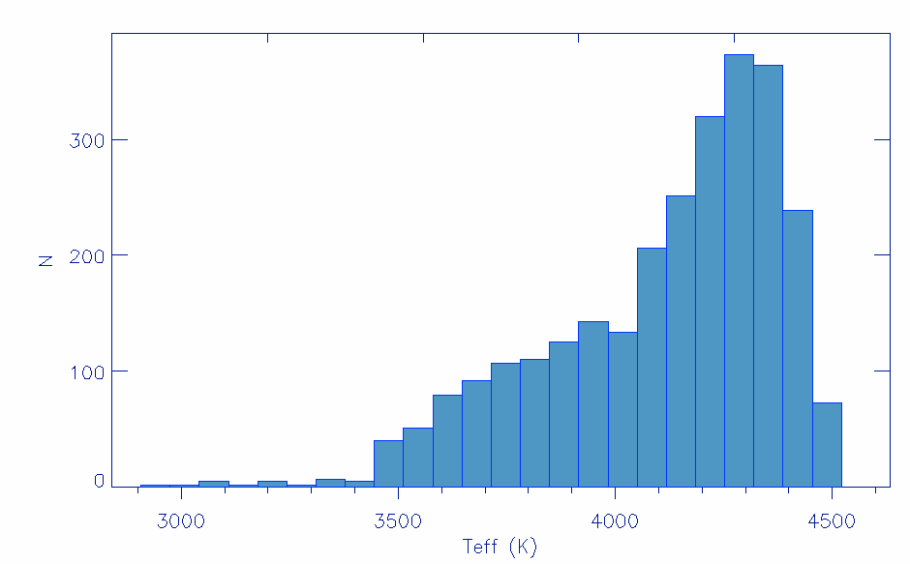
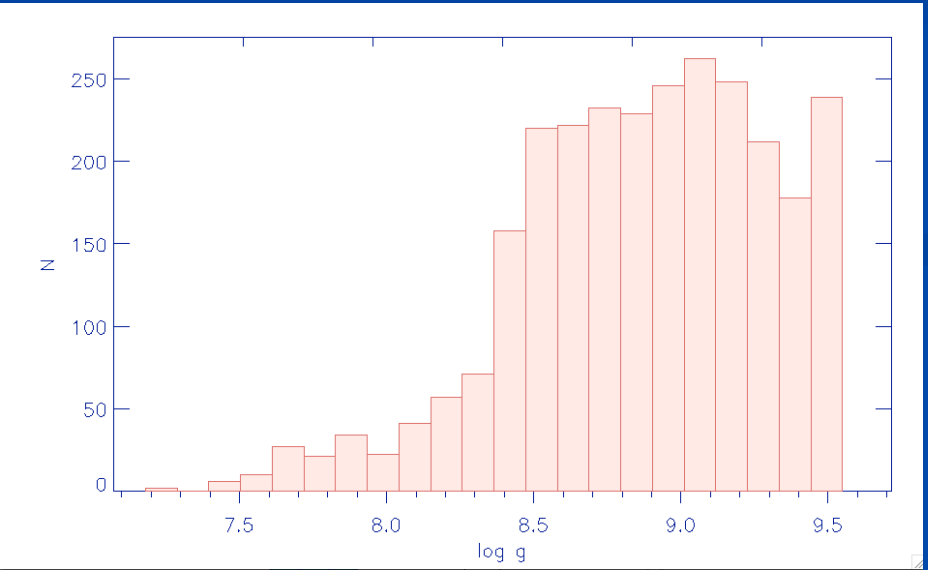




Coolest WD candidate found so far, 2900K

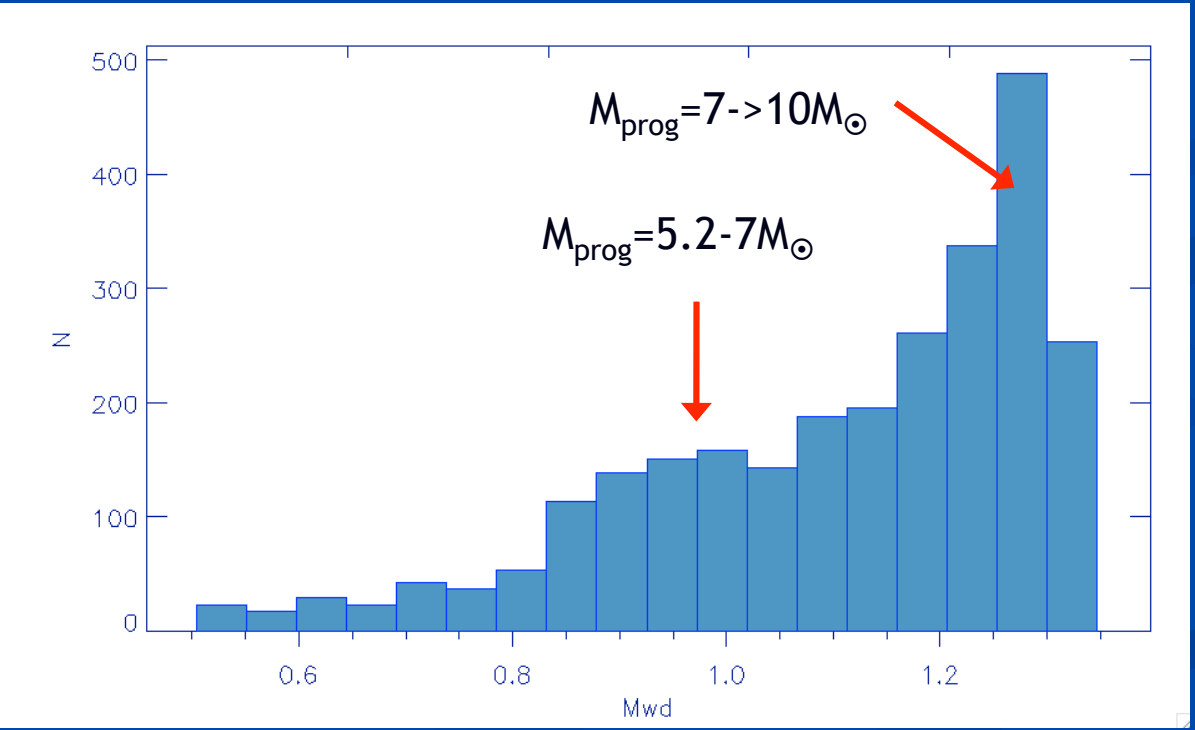
log g > 8.0 in most of the cases

WD masses + progenitor masses

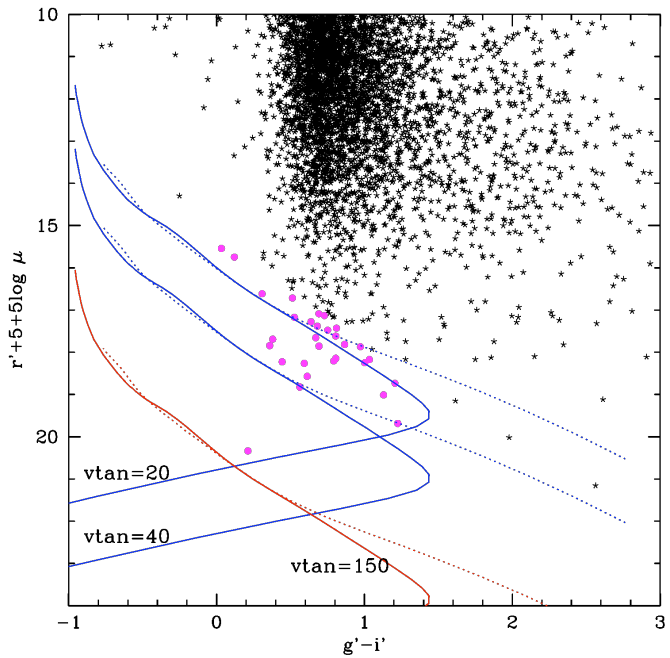
We obtain the WD masses using the cooling sequences of Fontaine et al. (2000) for CO core WDs (thick envelope)

M_{prog} by using the initial-final mass relationships:

Weidemann (2000), Ferrario et al. (2005), Kalirai et al.(2008), Catalán et al. (2008), etc…



Reduced proper motion diagram



Reduced proper motion diagram

Holberg & Bergeron (2006) models

Proper motion calculations in progress…

identify the membership of the WDs to a given population we use the rpm diagram:

$$H_r = r + 5 \log \mu + 5$$

Adopting boundary between subdwarfs and WDs:

$H_r > 2.68(g-i) + 15.21$ for $g-i<1.6$

$H_r > 10.0(g-i) + 3.5$ for $g-i>1.6$

20 WD candidates in SDSS, we expect to add many more to this list…

Future work

- improve proper motion calculations
- complete the optical imaging of the four WTS fields

  we will be in a position of ruling out or confirm IMFs predicting an overproduction of high mass stars down to the Kennicutt prescription
- spectroscopic follow-up of the coolest WD candidates to confirm their classification and study the atmospheric properties
- Hydrogen opacities are rather uncertain at low T_{effs}:
  - test WD model atmospheres
  - brown dwarfs atmospheres
- Apply this methodology to other surveys, e.g. ALHAMBRA survey (Moles et al. 2008): covers 4 square degrees with 20 contiguous, equal width, medium band photometric filters from 3500Å to 9700Å + JHK, which will provide detailed SEDs.
- Improve the initial-final mass relationship of pop. II WDs using the cool WDs detected

Danke!