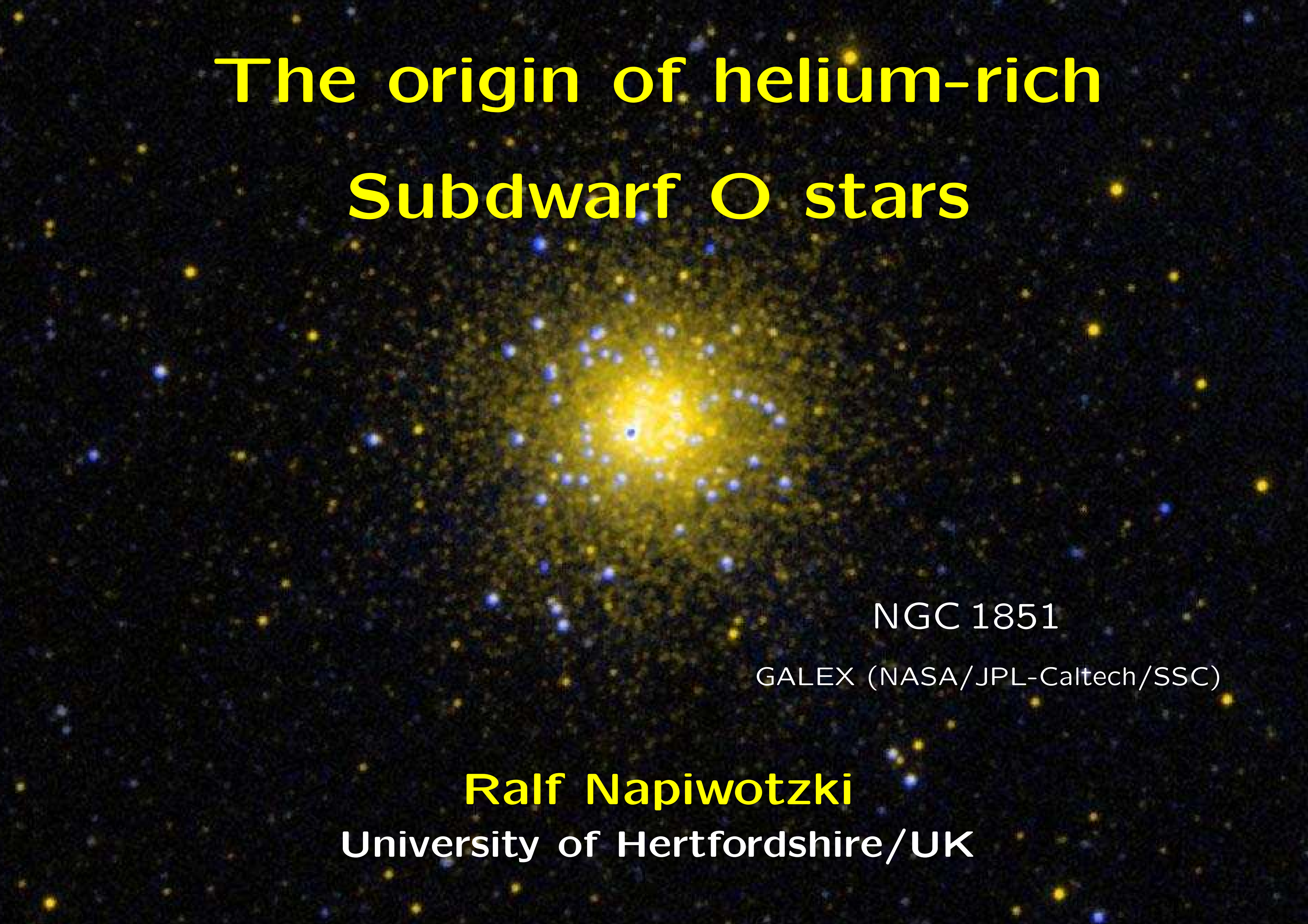
The origin of helium-rich Subdwarf O stars



NGC 1851

GALEX (NASA/JPL-Caltech/SSC)

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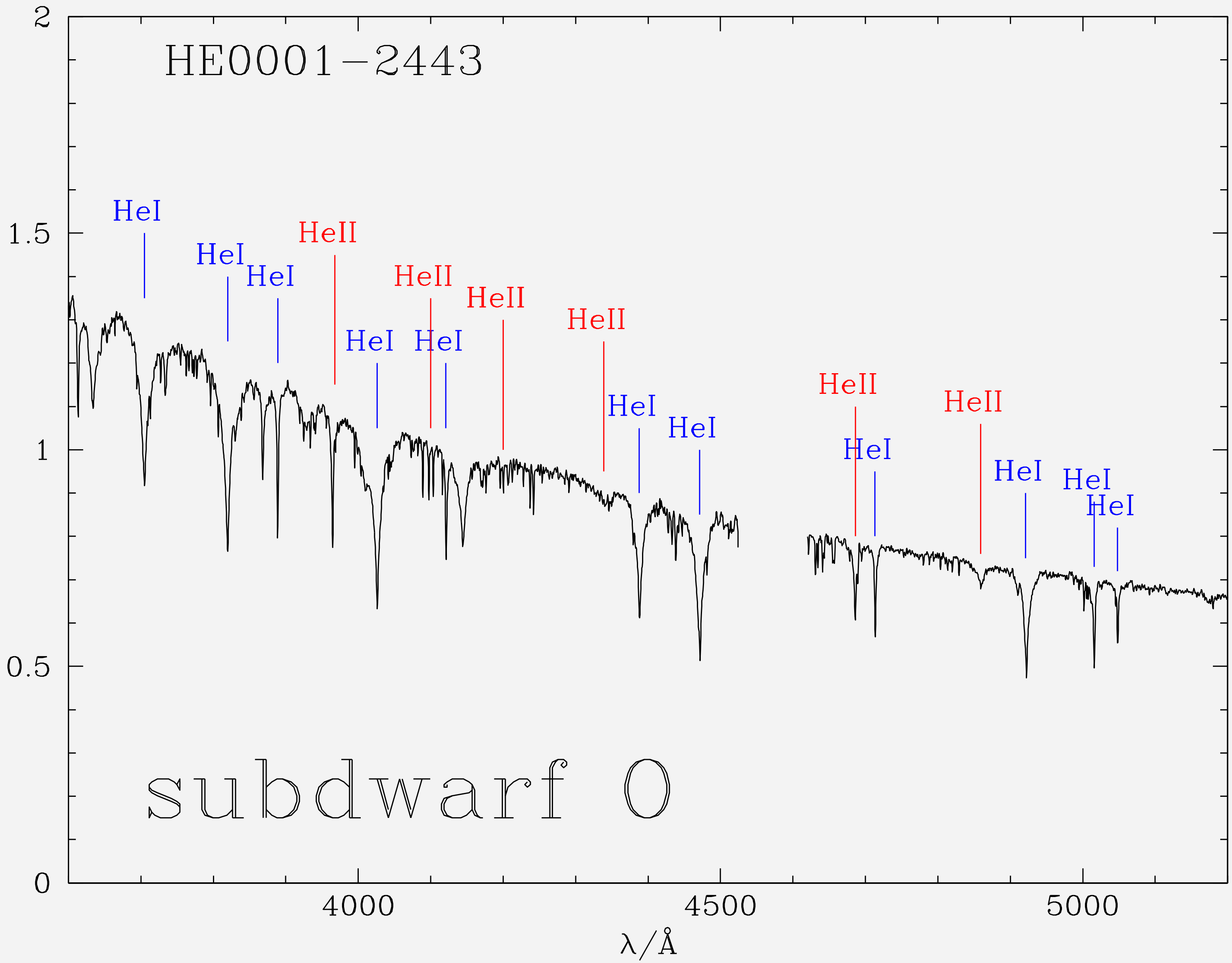
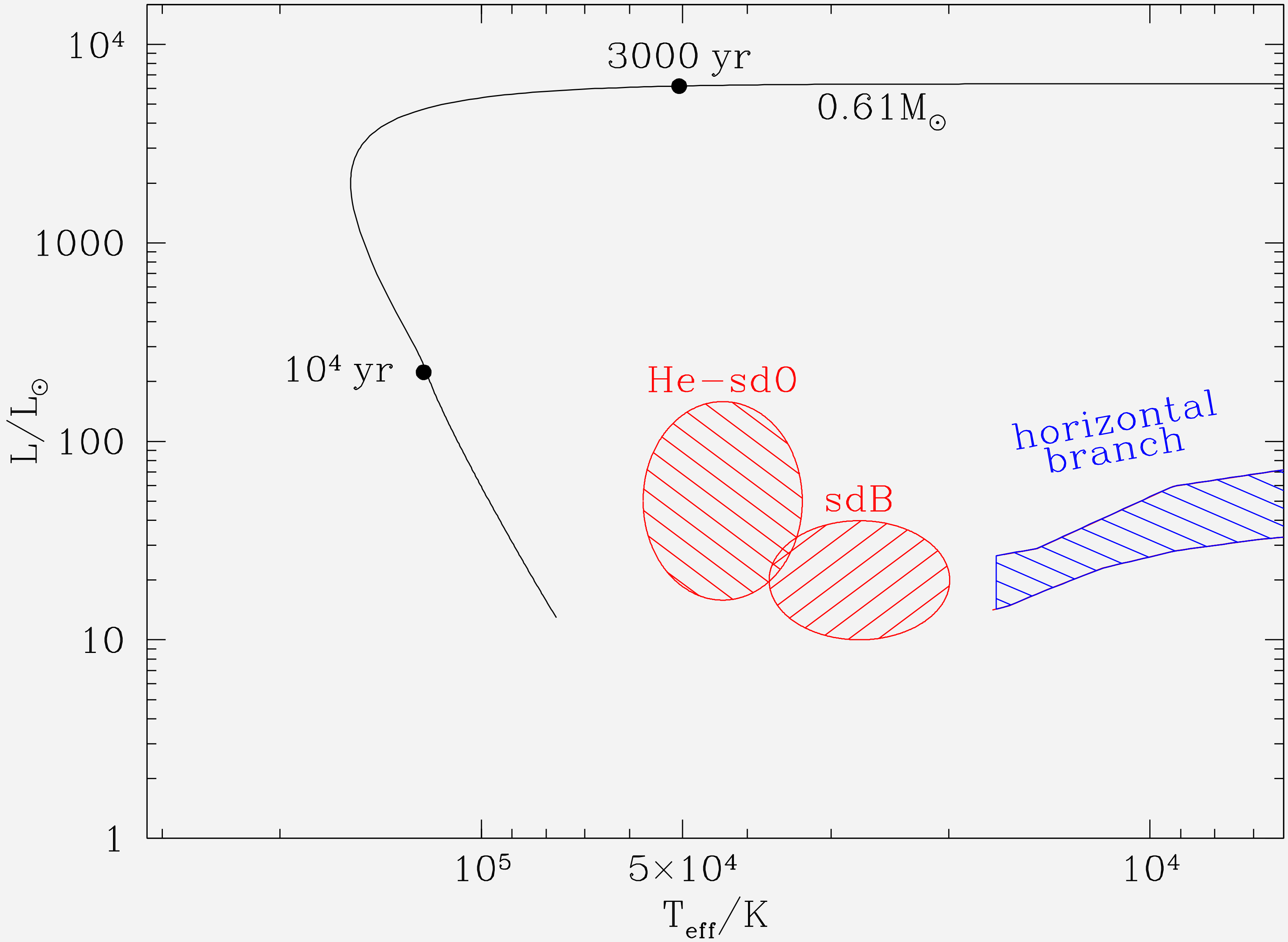
He–sdO stars

- The spectral class of "subdwarf O" stars includes all low mass, evolved stars, hot enough to produce HeII lines
- Mixed bag of stars with widely different parameters and evolutionary history
- Here: restrict to He-sdOs. Hot, helium-rich stars
- typical parameters: $T_{\mathrm{eff}} = 37000 - 55000$ K, $\log g = 5.5 - 6$, $L = 20 - 100 L_{\odot}$
- less well understood than sdBs. Partly, because of problems with modelling the spectra (until recently).
- space density virtually unknown

He–sdO stars



Hot stars: subdwarf B and O stars



Formation of He–sdO stars

- **post–sdB** stars. H envelope stripped off by weak wind and/or mixing processes (e.g. MacDonald & Arrieta 1994)
- **late flashers** (Castellani & Castellani 1993; D'Cruz et al. 1996). He-flash after the star left the RGB
- **Merging** of two He core white dwarfs. Ignition of He-burning after the merger (Saio & Jeffery 2000)

SN Ia Progenitor surveY

UVES at UT2/Kueyen of VLT

Large programmes
165.H-0588/167.D-0407
SPY consortium:
Napiwotzki (PI), Christlieb, Drechsel, Heber, Homeier, Karl, Koester, Leibundgut, Marsh, Moehler, Nelemans, Pauli, Renzini, Reimers, Yungelson

(Bamberg/D, ESO, Kiel/D, Göttinge/D, Hamburg/D, Hertfordshire/UK, Moscow/RUS, Nijmegen/NL, Warwick/UK)

SPY – ESO SN Ia Progenitor Survey

SPY project with UVES at the VLT

- high resolution echelle-spectrograph
- mounted at 8 m UT2 of ESO VLT
- $2''$ slit $\Rightarrow$ resolution at H$_\alpha$ ≤ 0.3 Å
- observations of more than 1000 WDs
- we took two spectra in different nights

Typical accuracy of ΔRV: $\approx$2 km/s

Systematic errors: $\sigma(RV) \leq 0.7$ km/s (telluric lines)

SPY sample of sdBs and sdOs

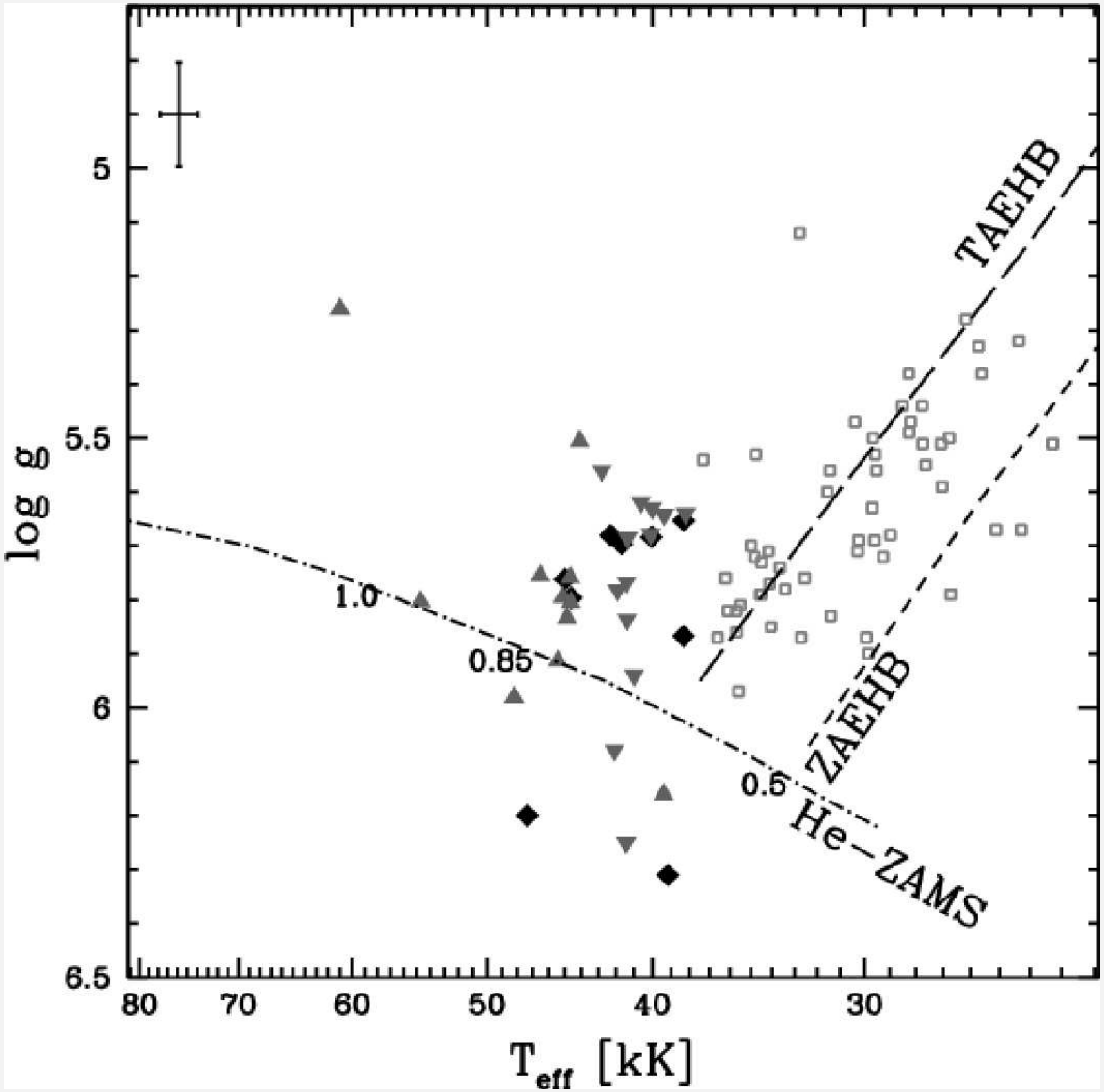
- The aim of SPY is the check of the double degenerate (DD) scenario for progenitors of supernova type Ia

- In the DD scenario two white dwarfs in a close binary merger due to orbital decay caused by gravitational wave radiation

- A total of **1014** white dwarf candidates was observed

-  SPY sample “contaminated” by **78 sdBs** and **33 He–sdOs**

Temperature & gravity



Stroeer et al. (2007)

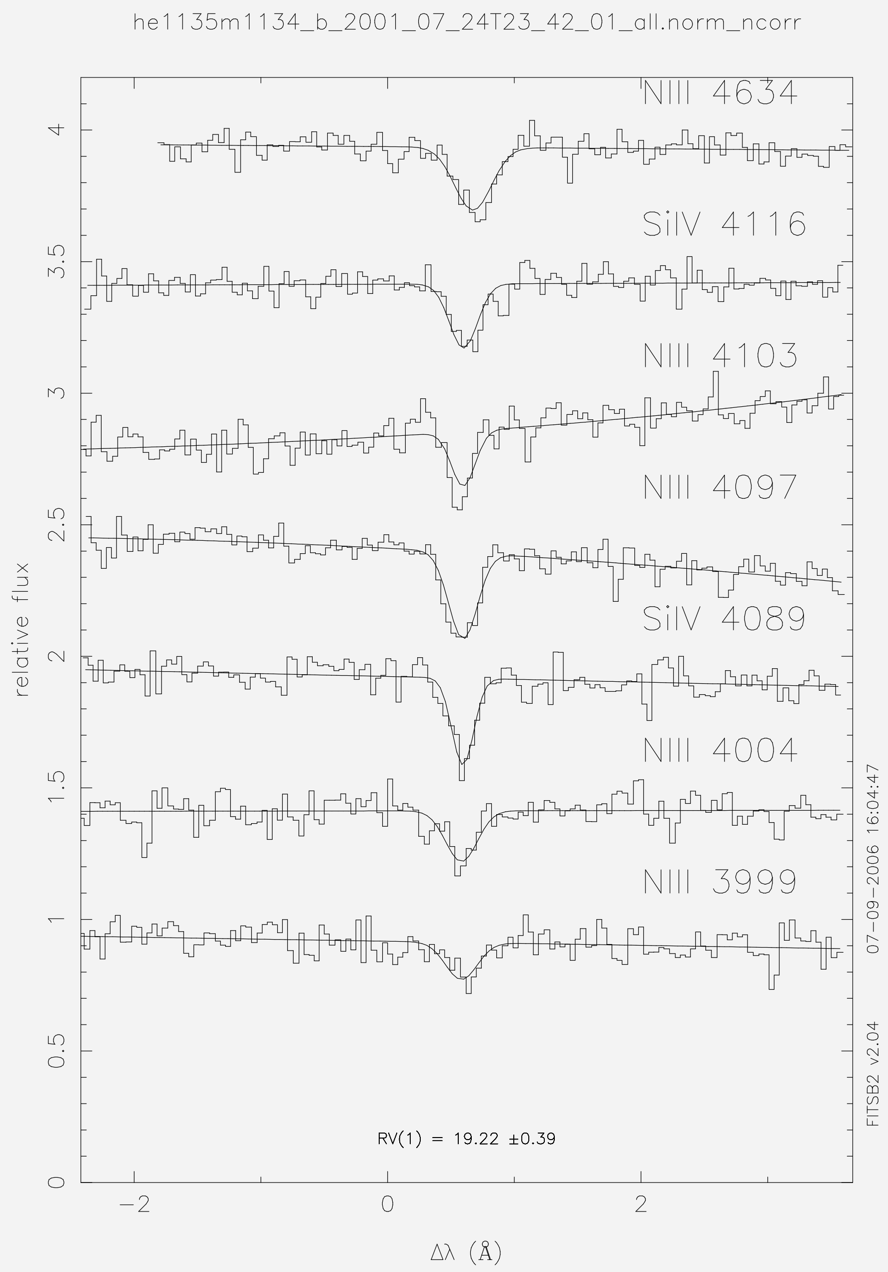
Abundances

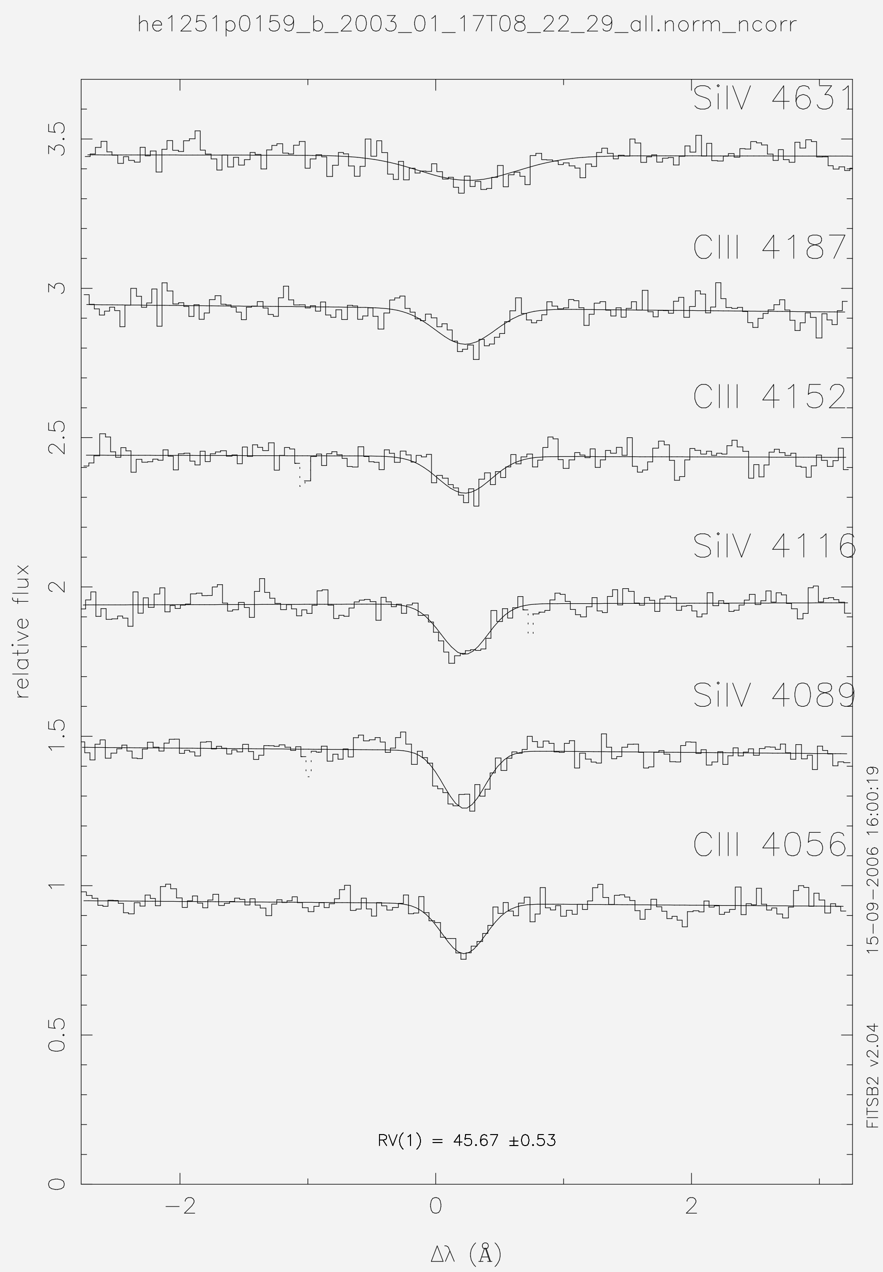
Abundance classification:

class		N
C	C lines present	11
N	N lines present	13
C&N	C and N lines present	9
0	neither	0

Stroeer et al. (2007)

Radial velocity measurements





Binary sdBs and sdOs

Subdwarf B stars:

Maxted et al. (2001): $\approx 70\%$

Napiwotzki et al. (2004): $\approx 40\%$

Subdwarf O stars:

33 He-sdOs of which are

1 He-sdO +G/F companion

1 only one spectrum taken

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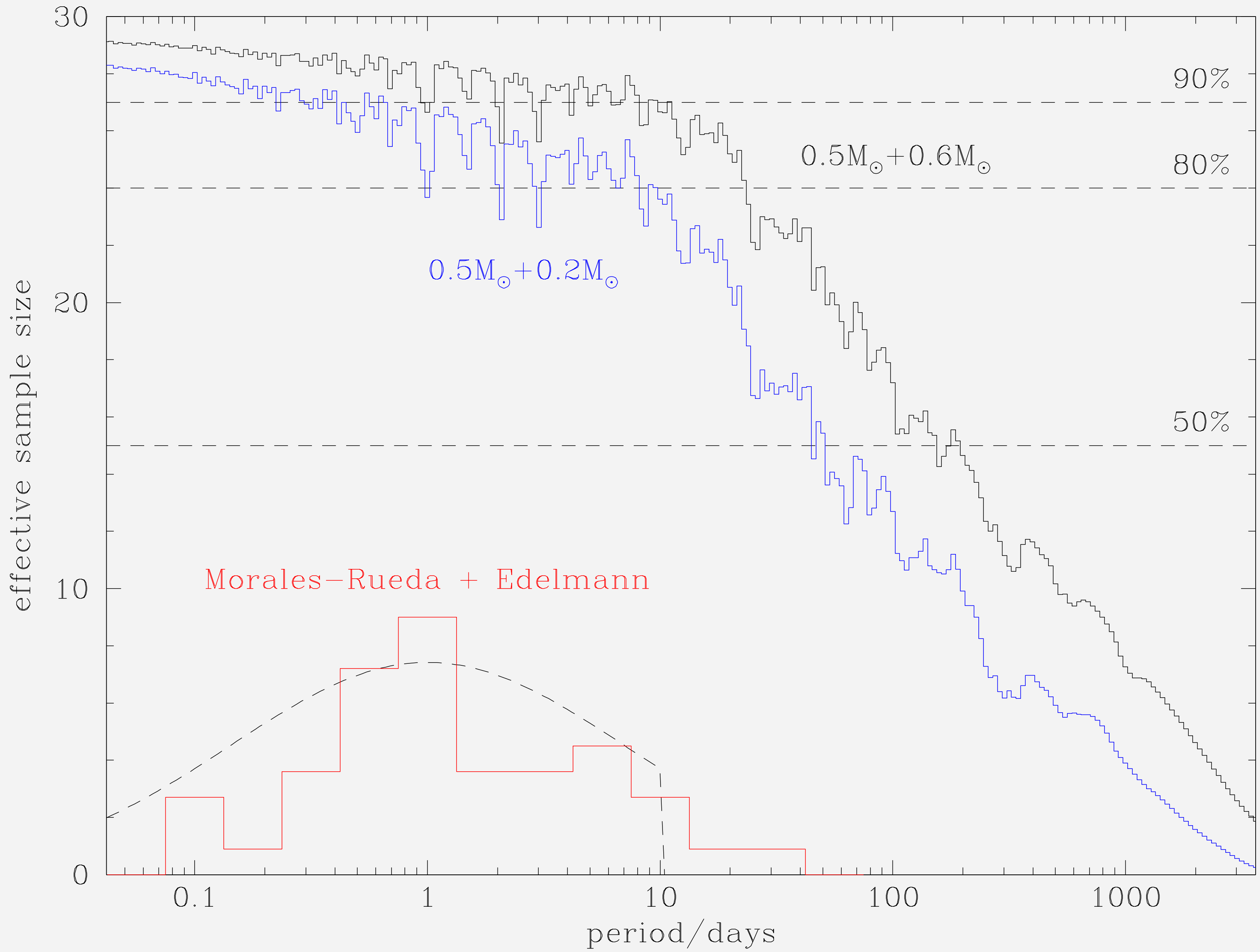
31 He-sdOs checked

1 RV variable binary sdO $\underline{\underline{= \mathbf{3\%}}}$

Note: the He-sdO binary is double lined and consists of **two He-sdOs** (Lisker et al. 2004). Another He-sdO+He-sdO binary known (Ahmad & Jeffery).

Corrections for detection efficiency



Corrections for detection efficiency

sdO $0.5M_\odot + 0.2M_\odot$	observed	efficiency	corrected
Gaussian	3%	89%	3%
Flat	3%	88%	3%

sdO $0.5M_\odot + 0.6M_\odot$	observed	efficiency	corrected
Gaussian	3%	94%	3%
Flat	3%	94%	3%

Binary sdBs and sdOs

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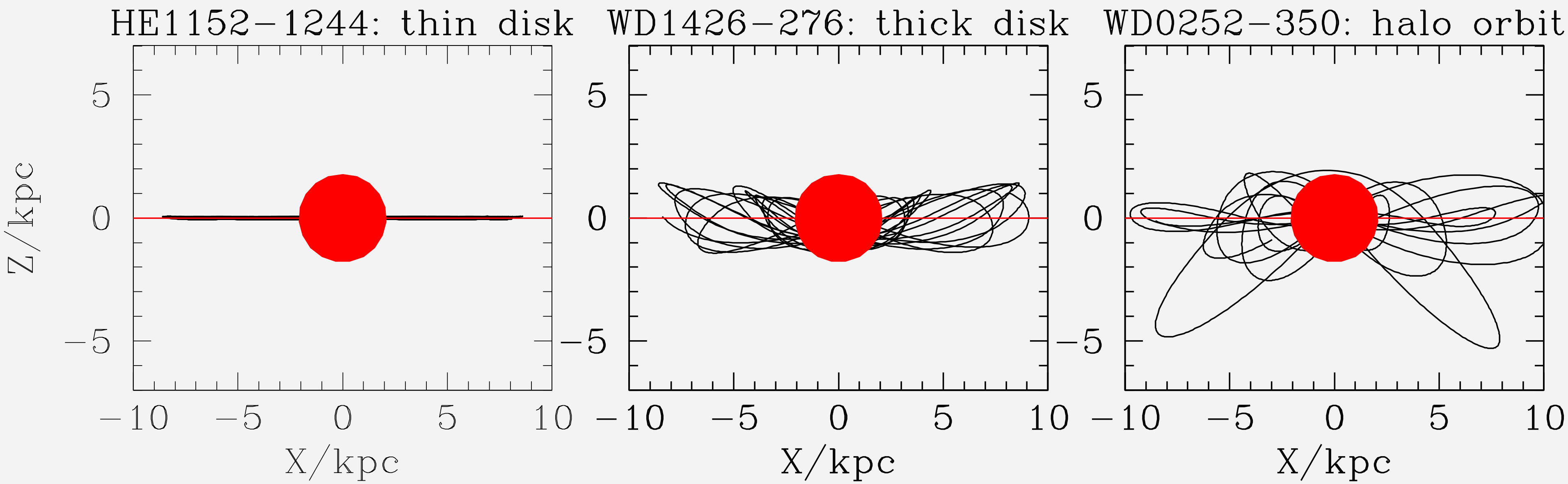
Kinematic classification



Kinematic classification – thin disk, thick disk, halo.

Criteria

- z–extend of orbit
- eccentricity
- angular momentum

Classification of sdB and sdO stars from SPY

Subdwarf B stars:

thin disk	54%	38–82%
thick disk	31%	21–46%
halo	15%	7–26%

He-sdO:

thin disk	32%
thick disk	39%
halo	29%

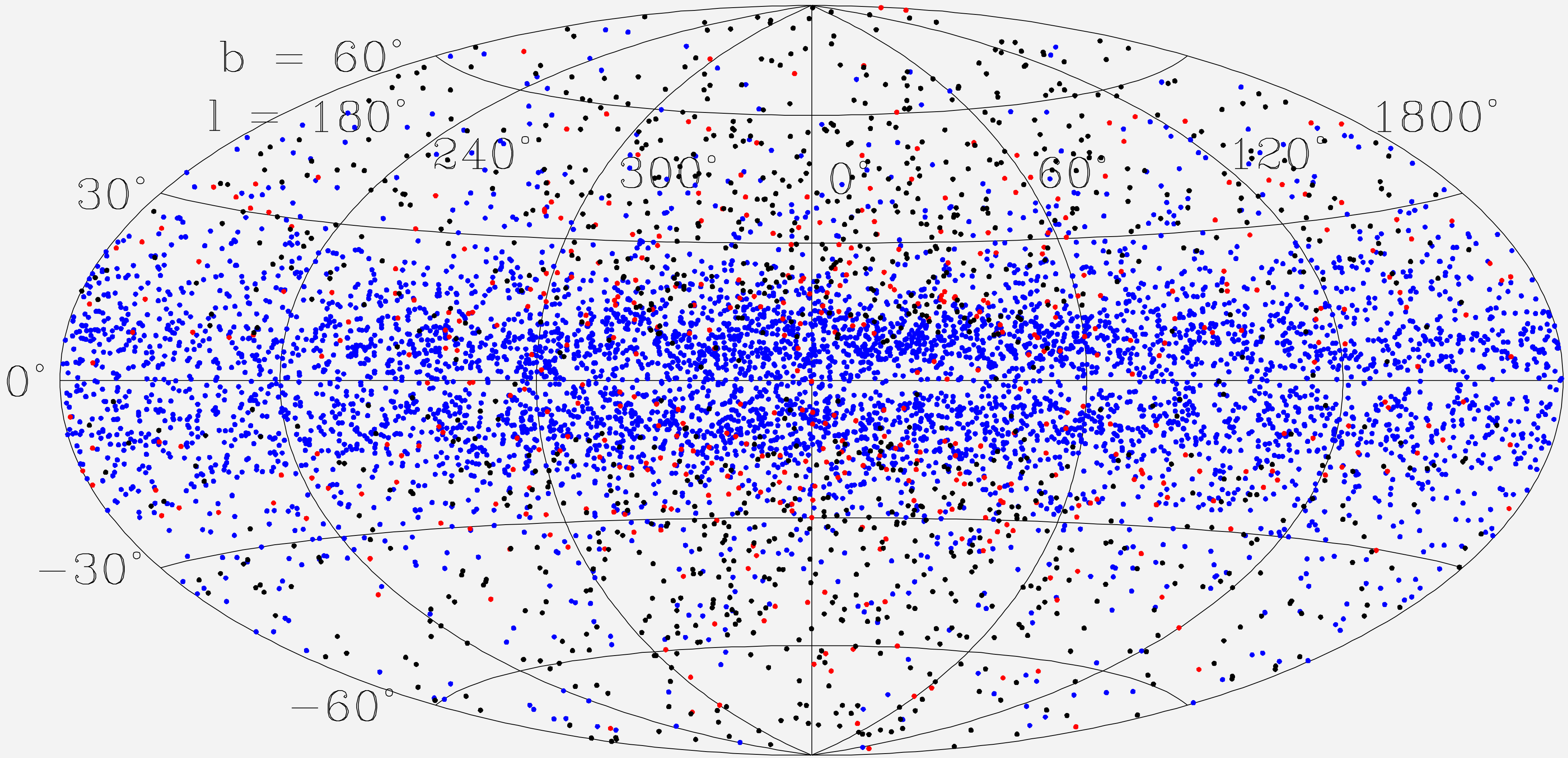
Large error limits. Classification of individual He-sdO stars often uncertain.

(Richter et al. 2006)

Simulated He-sdO population

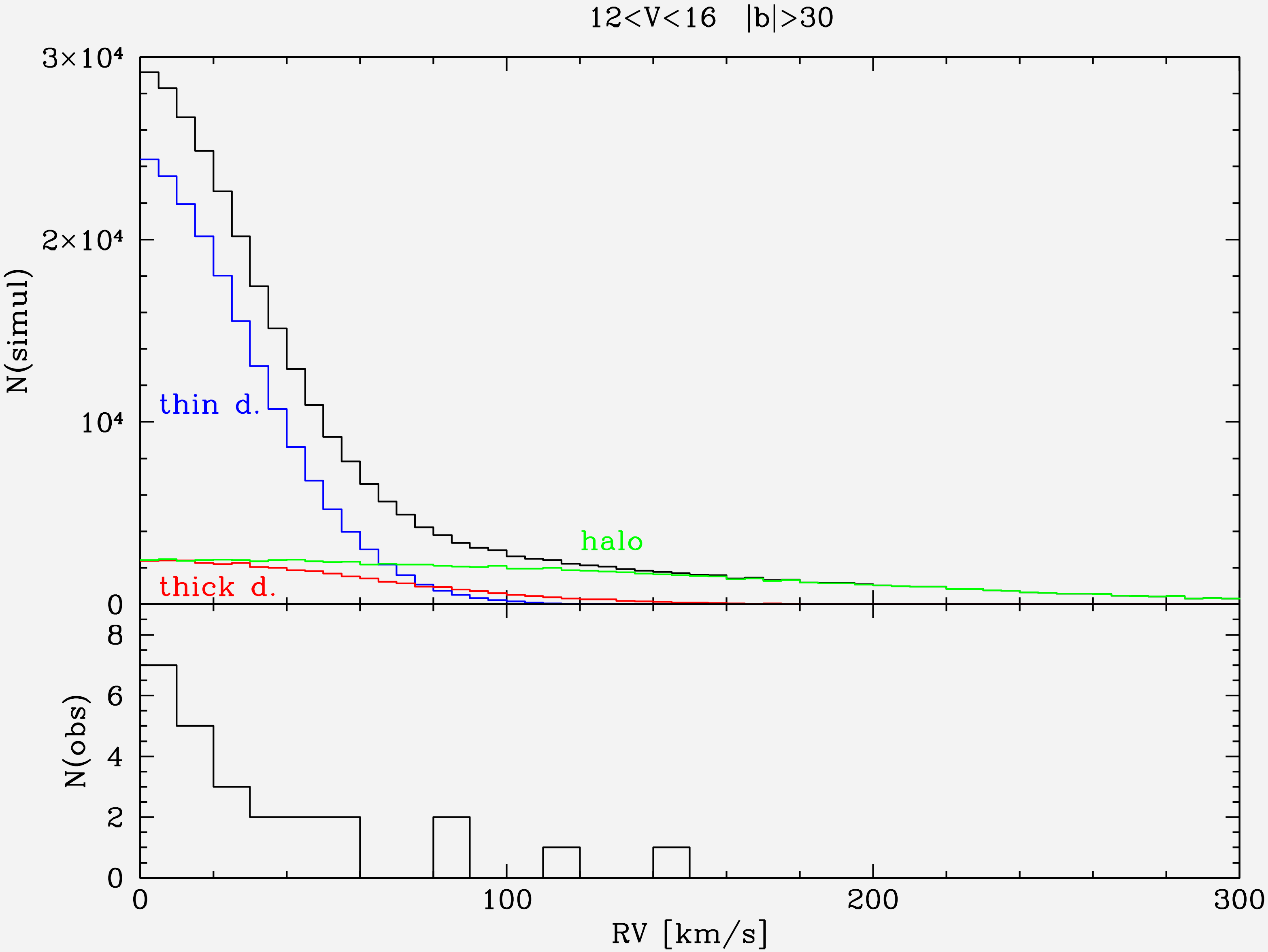
- Based on Besançon structure model of the Milky Way (Robin, et al. 2003)
- Local white dwarf density $\rho = 5.0 \cdot 10^{-3}\mathrm{pc}^{-3}$ (Holberg, Oswalt, & Sion 2002)
- Relative density of thin disk, thick disk, halo white dwarfs based on kinematic analysis of the SPY white dwarf sample (Pauli et al. 2003; Pauli et al. 2006)
- Two alternative hypotheses for the He-sdO space density
  - proportional white dwarf densities (≈merging)
  - stars are He-sdOs for first 100 Myr after leaving RGB/AGB (≈late He-flashers)

Simulated He-sdO population



• thin disk • thick disk • halo population

Simulated He-sdO population



Estimate of population memberships

Simplest case: 1000 stars selected from a small volume, i.e. no variation of densities – clear-cut classification.

	thin d.	thick d.	halo
probability	50%	20%	30%
N	500	200	300

Observed numbers should correspond to the **relative densities predicted** in the volume by the model population.

If not, the model has to be adjusted to get a **self consistent solution**.

Estimate of population memberships

Less simple case: 1000 stars selected from a small volume, i.e. no variation of densities – only probabilities p_i for individual stars.

$$N \longrightarrow \sum p_i$$

	thin d.	thick d.	halo
probability p	50%	20%	30%
$\sum p_i$	500	200	300

The probabilities p_i depend on the predicted model densities. Iteration is necessary.

Estimate of population memberships

More realistic case: each star is selected from a different volume with different relative densities.

$$N_{\text{pop}} \longrightarrow \sum \frac{N_{\text{pop}}}{N_{\text{total}}}$$

Same reasoning as before, but for each star individual densities and probabilities have to be computed.

Again, the probabilities p_i depend on the predicted model densities. Iteration is necessary.

For the self-consistent solution for each population should

$$\sum p_i^{\text{thin/thick/halo}} = \sum \frac{N_{\text{thin/thick/halo}}}{N_{\text{total}}} \tag{1}$$

Estimate of population memberships

Result for the SPY sample

thin disk	12.6
thick disk	12.1
halo	6.3

He-sdOs are produced by all stellar populations.

What didn't produce clear results so far: distinction between "merger" and "late He-flash" scenario" via population synthesis.

Halo population appears to be less productive by factor 2. . . 3.

Origin of He–sdOs

- Very low binary frequency (lower than in C/O white dwarfs)
- $\Rightarrow$ He–sdO are *not* the progeny of sdBs!
- He-sdOs are produced by all galactic populations
- Merging low mass white dwarfs appear to be a promising explanation
- Abundance classes C vs. N could point to different mixing processes during the merging.
- Formation channel for He–sdO + He–sdO binaries very different from single He–sdOs. He-sdOs in these systems likely not representative for "normal", single He-sdOs.