The origin of helium-rich Subdwarf O stars

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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: $T_{\text{eff}} = 37000 – 55000$ K, $\log g = 5.5 – 6$, $L = 20 – 100L_{\odot}$

Less well understood than sdBs. Partly, because of problems with modelling the spectra (until recently).

Space density virtually unknown.
He–sdO stars

HE0001−2443

subdwarf O

λ/Å
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)
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


UVES at UT2/Kueyen of VLT
SPY project with UVES at the VLT

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

Typical accuracy of $\Delta RV$: ≈2 km/s

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

<table>
<thead>
<tr>
<th>class</th>
<th>Description</th>
<th>$N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>C lines present</td>
<td>11</td>
</tr>
<tr>
<td>N</td>
<td>N lines present</td>
<td>13</td>
</tr>
<tr>
<td>C&amp;N</td>
<td>C and N lines present</td>
<td>9</td>
</tr>
<tr>
<td>0</td>
<td>neither</td>
<td>0</td>
</tr>
</tbody>
</table>

Stroeer et al. (2007)
Radial velocity measurements

$RV_1 = 19.22 \pm 0.39$

$RV_1 = 48.67 \pm 0.33$
**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

31 He-sdOs checked

1 RV variable binary sdO $= 3\%$

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

![Graph showing detection efficiency](image)

- Morales-Rueda + Edelmann
- $0.5M_\odot + 0.2M_\odot$
- $0.5M_\odot + 0.6M_\odot$
- 50%, 80%, 90%
## Corrections for detection efficiency

<table>
<thead>
<tr>
<th></th>
<th>sdO $0.5M_\odot + 0.2M_\odot$</th>
<th>sdO $0.5M_\odot + 0.6M_\odot$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>observed</td>
<td>efficiency</td>
</tr>
<tr>
<td>Gaussian</td>
<td>3%</td>
<td>89%</td>
</tr>
<tr>
<td>Flat</td>
<td>3%</td>
<td>88%</td>
</tr>
</tbody>
</table>
**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
- 31 He-sdOs checked
- 1 RV variable binary sdO $= 3\%$

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). (Philipp Podsiadlowski: double-core envelope ejection of $\approx 5M_\odot + 5M_\odot$ binary)
Kinematic classification

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 $\rho = 5.0 \cdot 10^{-3} \text{pc}^{-3}$ (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 ($\approx$merging)
  - stars are He-sdOs for first 100 Myr after leaving RGB/AGB ($\approx$late He-flashers)
Simulated He-sdO population

- thin disk
- thick disk
- halo population
Simulated He-sdO population

12 < V < 16 \quad |b| > 30

The graph shows the distribution of velocities (RV) for different populations:
- **thin d.**
- **thick d.**
- **halo**

The y-axis represents the number of simulated objects (N(simul)) and the number of observed objects (N(obs)). The x-axis represents the RV in km/s.
Estimate of population memberships

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

<table>
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<tr>
<th>probability</th>
<th>thin d.</th>
<th>thick d.</th>
<th>halo</th>
</tr>
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<tbody>
<tr>
<td>N</td>
<td>500</td>
<td>200</td>
<td>300</td>
</tr>
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</table>

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

\[ N \rightarrow \sum p_i \]

<table>
<thead>
<tr>
<th>probability $p$</th>
<th>thin d.</th>
<th>thick d.</th>
<th>halo</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>20%</td>
<td>30%</td>
<td></td>
</tr>
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</table>

| $\sum p_i$      | 500     | 200      | 300  |

The probabilities $p_i$ depend on the predicted model densities. Iteration is necessary.
More realistic case: each star is selected from a different volume with different relative densities.

\[ N_{\text{pop}} \rightarrow \sum \frac{N_{\text{pop}}}{N_{\text{total}}} \]

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

\[ \sum p_i^{\text{thin/thick/halo}} = \sum \frac{N_{\text{thin/thick/halo}}}{N_{\text{total}}} \] (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.