Abundance structure of the atmospheres of magnetic CP stars

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Temperature dependence of the mean Cr and Fe abundances in the atmospheres of Ap stars.
(Ryabchikova, 2005, Astr. Letters, 31, 388)
Theoretical distributions of the chosen elements derived in self-consistent diffusion model atmosphere calculations:

According to LeBlanc & Monin. 2004, IAU Symp.224, 193-200
Outline of the talk

- Results of the element stratification analysis in the atmospheres of Ap stars and comparison with the diffusion theory predictions

- Isotope's separation in the atmospheres of CP stars

- Heavy elements in Przybylski's star
Ca in Ap star HD 176232 (10 Aql)
Methods of the stratification analysis:

1. Step function approximation (after J. Babel 1992, a code DDAFIT written by Kochuchov (see Ryabchikova et al. 2005))

Ca II 3933 line in Ap stars
Up to now stratification analysis was performed for the following groups of stars:

**PGa stars:** He

**HgMn stars:** Mn increase towards the upper atmosphere

**HB stars:** S concentration in the upper layers
Fe concentration in the deeper layers
(Khalack et al. 2007, A&A 466, 667)

**Ap stars:** Mg, Si, Ca, Ti, Cr, Mn, Fe, Ba, Pr, Nd

**Ca stratification is derived in the atmospheres of 25 stars:**
(Ryabchikova et al. 2001, 2007; Cowley et al. 2007)
Examples of the empirically derived Cr and Fe stratifications: comparison with the diffusion predictions.
Fe distribution in the stars with different magnetic field intensity.
Examples of the empirically derived Si stratifications: comparison with the diffusion predictions.
Examples of the empirically derived Ca stratifications: comparison with the diffusion predictions.
Pr-Nd anomaly in the atmospheres of cool Ap stars:

From Ryabchikova et al. (2004)

NLTE effects on Nd II and Nd III populations

Element distribution in the atmosphere of typical cool Ap star (HD24712)
\(^3\text{He}/^4\text{He} \) anomaly in hot stars

HR 7465 (15500g37) – top

\( ^3\text{He} \): -0.90 ( -2.36 < logt < -1.64); -2.20 (logt > -1.64)  
\( ^4\text{He} \): -2.00 ( logt < -0.23); -1.10 (logt > -0.23)

3 Cen A (17500g41) - bottom

\( ^3\text{He} \): -1.10 ( -2.65 < logt < -1.16); -2.50 (logt > -1.16)  
\( ^4\text{He} \): -1.40 ( -0.52 < logt < 0.7); -2.00 (logt > 0.7)

Taken from:

First, Ca isotopes in IR triplet lines were found in HgMn stars by Castelli & Hubrig (2004)

In cool Ap stars wavelength shifts due to $^{48}$Ca isotope were reported by Cowley & Hubrig (2005) and studied extensively by Cowley et al. (2007). These authors derived Ca stratification for 2 Ap stars.

Full analysis of Ca stratification + isotopic modelling for 23 Ap stars was performed by Ryabchikova, Kochukhov & Bagnulo (2005, 2007).
Ca II 8498 line in 10 Aql.

Blue line represents synthetic line profile calculated with the Ca stratification shown below by black line.

Ca stratification derived from the Ca optical lines.
Ca II 8498 line in 10 Aql.
Ca II 8498 line in spectra of Ap stars with $T_{\text{eff}} < 9500$ K
Ca II 8498 line in spectra of Ap stars with $T_{\text{eff}} > 9500$ K
Conclusions

1. The atmospheres of magnetic Ap stars are chemically stratified

2. Elements may be concentrated in the deeper as well as in the upper atmospheric layers

3. Abundance stratification study with the concentration in the upper atmosphere requires NLTE

4. We observe the separation of the isotopes in Ap atmospheres, which disappears when magnetic field exceeds ~6 kG

5. Differential stratification of the isotopes may be caused by a combined effect of the diffusion and light-induced drift (LID)
Heavy elements in Ap stars.

Tc and Pm identification on by wavelength coincidence statistics (WCS) – Cowley et al. (2004) in Przybylski’s star and HD 965

Available atomic data for the short-lived elements:
Tc I: Palmeri et al. (2005)
Tc II: Palmeri et al. (2007)
Pm II: Fivet et al. (2007)

If short-lived elements are really present, the nuclear synthesis rather than the diffusion is responsible for the observed heavy elements sequence.

In scenario proposed by Goriely (2007) the observed abundance pattern in Przybylski's star may be explained assuming that extremely high proton and -particle fluences have irradiated solar-like material. However, this scenario would require flares with a magnetic field \( > 10^6 \) G (\(|B|=2300 \) G) and the energy flux \( F \sim 10^{17} \) erg cm\(^{-2}\) s\(^{-1}\) (total star radiation is \( 10^{11} \) erg cm\(^{-2}\) s\(^{-1}\))
Tc I in Przybylski' star (HD101065)

Yushchenko et al. 2007, NIC-IX, poster

All Tc II strongest lines in 3000-10000 Å fall very close to the position of strong REE or other anomalous species (Co I, Ru I).
From 8 strongest Pm II lines from Fivet et al. (2007) for 4 lines abundances may be estimated and provided an upper limit for Pm abundance $\log(Pm/N_{\text{tot}})=-9.5$. This is by 2-3 orders smaller than the Nd abundance (element, from which Pm may be synthesized through neutron capture). Goriely (2007) predicts the Pm abundance should be smaller by ~1 dex.

Cowley et al. (2005) suggested Pm 2 identification for 2 features measured in Przybylski’s star at 6659.07 and 6772.28.
Pm in Przybylski’s star
Przybylski's star is known to be the coolest among the Ap stars and to be the richest in rare-earth elements. Most of the REE are observed in the second and the third ionisation stage. The laboratory measurements of these species are very scarse.

For instance, from 13700 classified Ce II lines in 3000 – 10000 Å region about 10000 lines are present in the spectrum of Przybylski's star with the intensities higher than 5 %.

All known Nd II (1284), Sm II (1327), Gd II (890) are present with the intensities more than 20 %. About 10000 lines of these species are expected (they are obtained in the laboratory spectra but not yet classified), which will improve the situation with the line identification.

The best studied second ion, Pr III, has about 1000 classified lines and 300 are measured in PS, while we know only 70 classified lines of Nd III (the most abundant rare-earth element in PS).

New extensive study of the REE spectra are required before definite identifications of the short-lived radioactive elements.
How to study abundance stratification empirically?
Comparison between the observed and computed line profiles.

**Nd II 5319**

- Observations -- black line,
- LTE calculations in stratified atmosphere -- blue dashed line
- NLTE calculations in stratified atmosphere -- red line

**Nd III 5294**
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