

Lanthanides in stellar atmospheres

T. Ryabchikova

Institute of Astronomy
Russian Academy of Sciences



Lanthanides or the rare-earth elements (REE) constitute a compact group of 15 elements from the 6th period of Mendeleev table.

All REEs but Pm have stable isotopes and are observed in solar and stellar atmospheres.

1	IA																VIII A						18			
1	1																	2								
	1.0079																	4.0026								
	1s																	1s								
	H																	He								
	HYDROGEN																	HELIUM								
2	IIA																		IIIA		14	IVA	15	VIA	17	VIIA
	3	4																	5	6	7	8	9	10		
	6.941(2)	9.0122																	10.811	12.011	14.007	15.999	18.998	20.180		
	[He] 2s	[He] 2s																	[He] 2s 2p	[He] 2s 2p	[He] 2s 2p	[He] 2s 2p	[He] 2s 2p	[He] 2s 2p		
	Li	Be																	B	C	N	O	F	Ne		
	LITHIUM	BERYLLIUM																	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	NEON		
3	11	12																	13	14	15	16	17	18		
	22.990	24.305																	26.982	28.086	30.974	32.065	35.453	39.948		
	[Ne] 3s	[Ne] 3s																	[Ne] 3s 3p	[Ne] 3s 3p	[Ne] 3s 3p	[Ne] 3s 3p	[Ne] 3s 3p	[Ne] 3s 3p		
	Na	Mg																	Al	Si	P	S	Cl	Ar		
	SODIUM	MAGNESIUM																	ALUMINIUM	SILICON	PHOSPHORUS	SULFUR	CHLORINE	ARGON		
4			VIII B																							
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36								
	39.098	40.078	44.956	47.867	50.942	51.996	54.938	55.845	58.933	58.693	63.546	65.409	69.723	72.64(1)	74.922	78.96(3)	79.904	83.798								
	[Ar] 4s	[Ar] 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s	[Ar] 3d 4s 4p	[Ar] 3d 4s 4p	[Ar] 3d 4s 4p	[Ar] 3d 4s 4p	[Ar] 3d 4s 4p	[Ar] 3d 4s 4p								
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr								
	POTASSIUM	CALCIUM	SCANDIUM	TITANIUM	VANADIUM	CHROMIUM	MANGANESE	IRON	COBALT	NICKEL	COPPER	ZINC	GALLIUM	GERMANIUM	ARSENIC	SELENIUM	BROMINE	KRYPTON								
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54								
	85.468	87.62(1)	88.906	91.224	92.906	95.94(2)	(98)	101.07(2)	102.906	106.42(1)	107.868	112.411	114.818	118.710	121.760	127.60(3)	126.904	131.293								
	[Kr] 5s	[Kr] 5s	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d	[Kr] 4d 5s	[Kr] 4d 5s	[Kr] 4d 5s 5p	[Kr] 4d 5s 5p	[Kr] 4d 5s 5p	[Kr] 4d 5s 5p	[Kr] 4d 5s 5p	[Kr] 4d 5s 5p								
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe								
	RUBIDIUM	STRONTIUM	YTTORIUM	ZIRCONIUM	NIوبيUM	MOLYBDENUM	TECHNETIUM	RUTHENIUM	RHODIUM	PALLADIUM	SILVER	CADMIUM	INDIUM	TIN	ANTIMONY	TELLURIUM	IODINE	XENON								
6	55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86								
	132.905	137.327		178.49(2)	180.947	183.84(1)	186.207	190.23(3)	192.227	195.084	196.967	200.59(2)	204.383	207.2(1)	208.980	(209)	(210)	(222)								
	[Xe] 6s	[Xe] 6s		[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 5d 6s 6p	[Xe] 4f 5d 6s 6p	[Xe] 4f 5d 6s 6p	[Xe] 4f 5d 6s 6p	[Xe] 4f 5d 6s 6p	[Xe] 4f 5d 6s 6p								
	Cs	Ba	Lanthanides	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn								
	CESIUM	BARIUM		HAFNIUM	TANTALUM	TUNGSTEN	RHENIUM	OSMIUM	IRIDIUM	PLATINUM	GOLD	MERCURY	THALLIUM	LEAD	BISMUTH	POLONIUM	ASTATINE	RADON								
7	87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118								
	(223)	(226)		(261)	(262)	(266)	(264)	(277)	(268)	(281)	(272)	(285)	(284)	(289)	(288)	(292)		(294)								
	[Rn] 7s	[Rn] 7s		[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 6d 7s								
	Fr	Ra	Actinides	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Uuq	Uup	Uuh	Uus*	Uuo								
	FRANCIUM	RADIUM		RUTHERFORDIUM	DUBNIUM	SEABORGIUM	BOHRIUM	HASSIUM	MEITNERIUM	DARMSTADIUM	ROENTGENIUM	COPERNICIUM	UNUNTRIUM	UNUNQUADIUM	UNUNPENTIUM	UNUNHEXIUM	UNUNSEPTIUM	UNUNOCTIUM								

LANTHANIDES

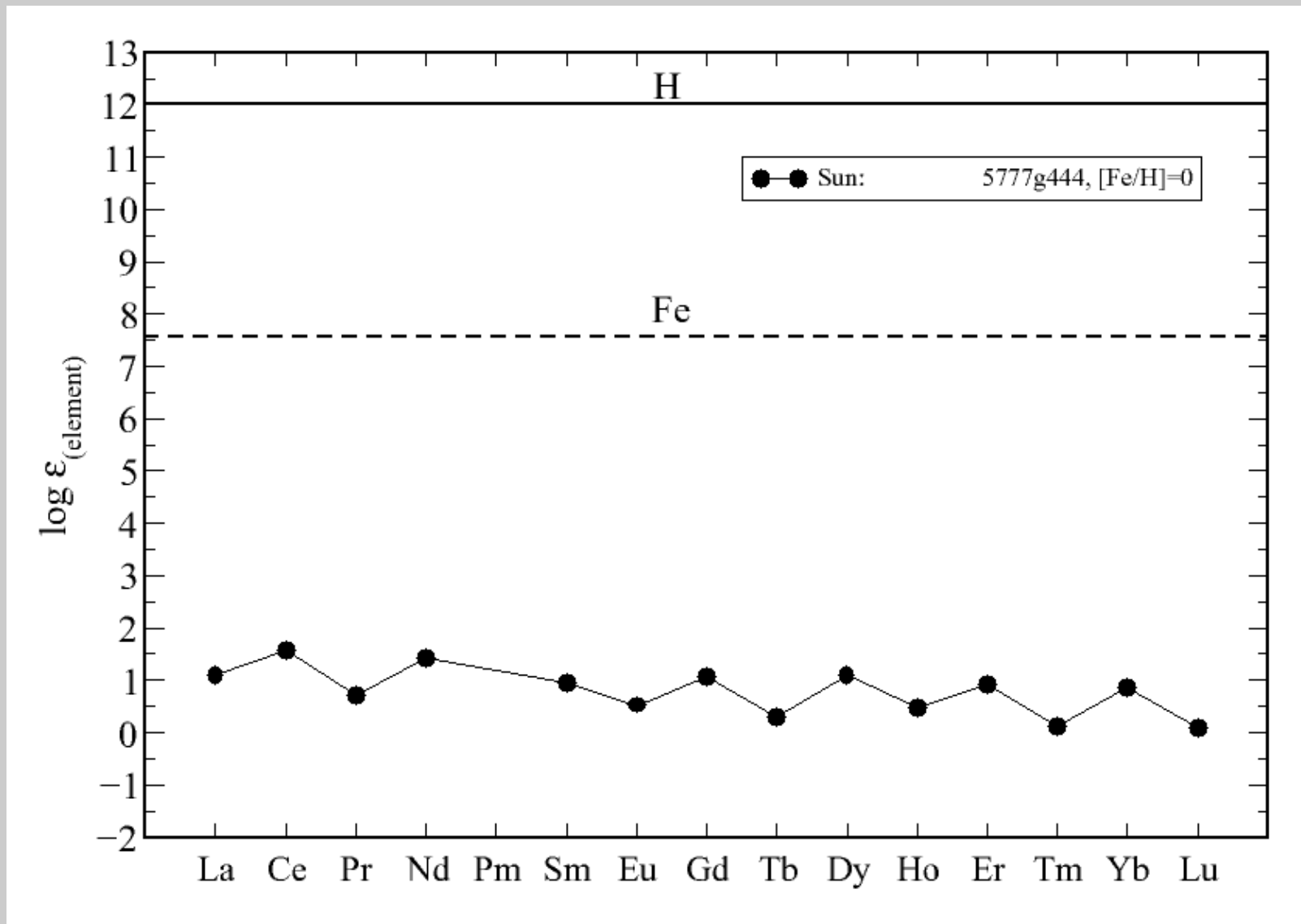
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
138.905	140.116	140.908	144.242	(145)	150.36(2)	151.964	157.25(3)	158.925	162.500	164.930	167.259	168.934	173.04(3)	174.967
[Xe] 5d 6s	[Xe] 4f 5d 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 5d 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 6s	[Xe] 4f 5d 6s
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
LANTHANUM	CERIUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	YTTREBIUM	LUTETIUM

ACTINIDES

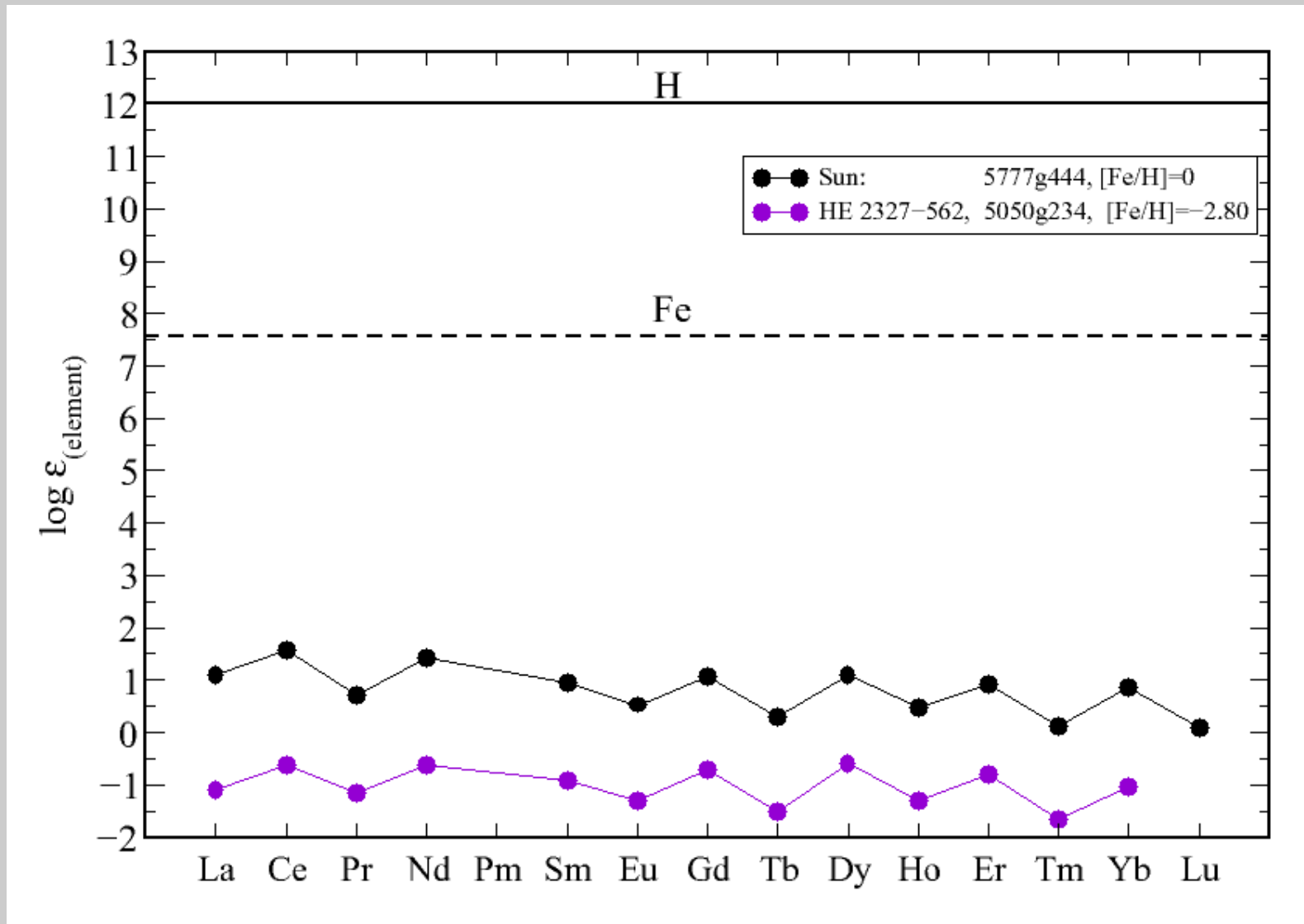
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
(227)	232.038	231.036	238.029	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)
[Rn] 6d 7s	[Rn] 6d 7s	[Rn] 5f 6d 7s	[Rn] 5f 6d 7s	[Rn] 5f 6d 7s	[Rn] 5f 7s	[Rn] 5f 7s	[Rn] 5f 6d 7s	[Rn] 5f 7s	[Rn] 5f 7s	[Rn] 5f 7s	[Rn] 5f 7s	[Rn] 5f 7s	[Rn] 5f 7s	[Rn] 5f 7s
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
ACTINIUM	THORIUM	PROTACTINIUM	URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MENDELEVIUM	NOBELIUM	LAWRENCIUM

"The Periodic Table through Space and Time", September 10-13, St. Petersburg

REE abundances in solar atmosphere



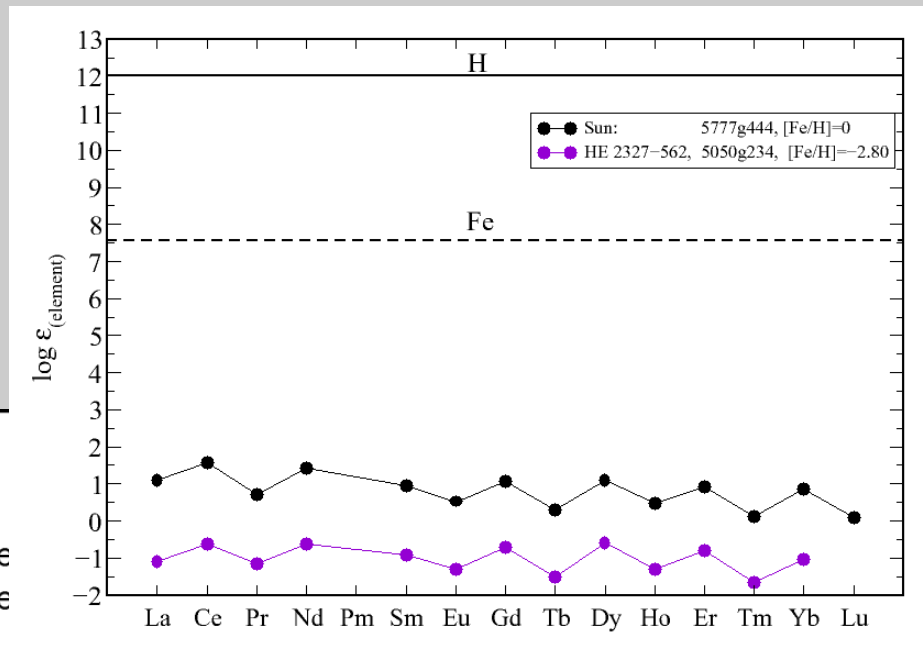
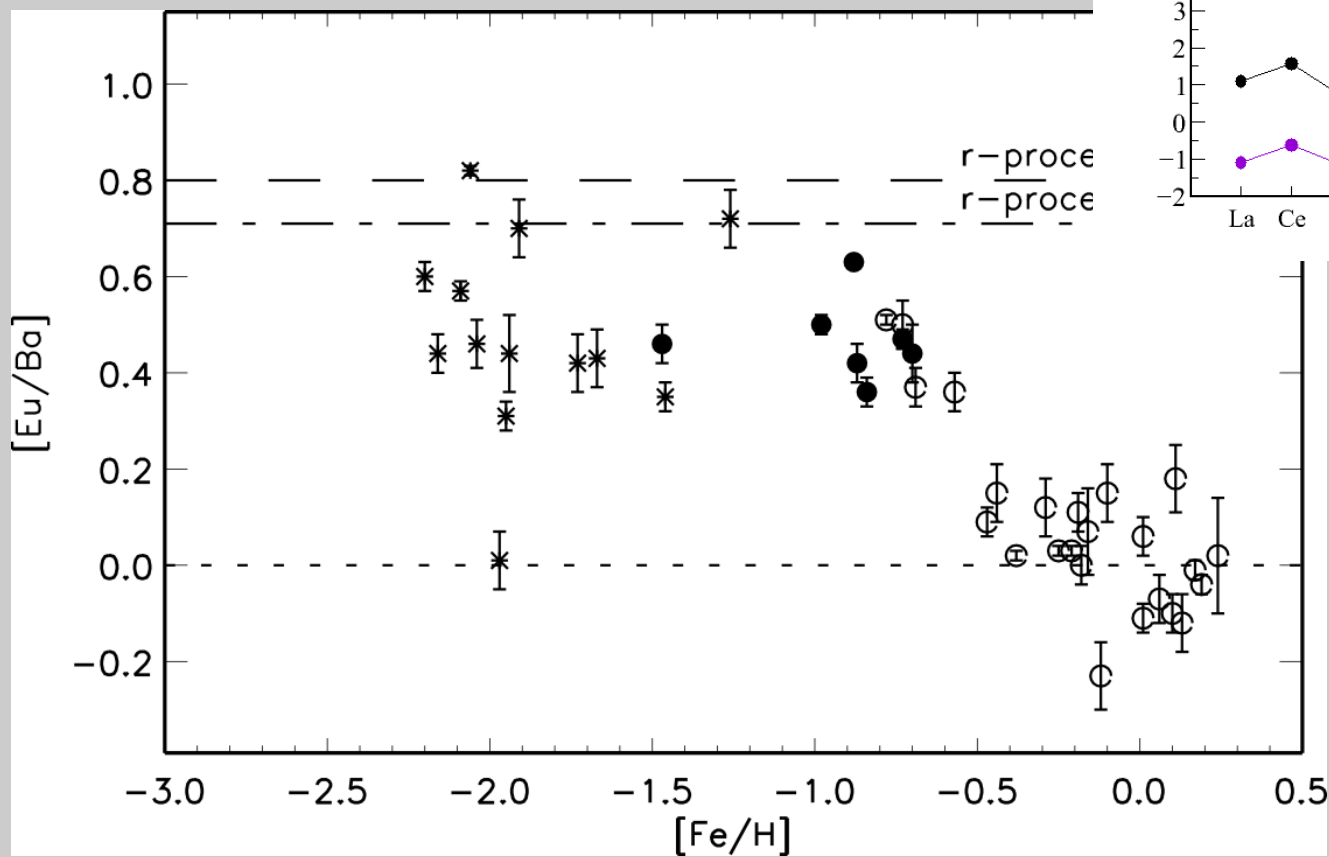
REE abundances in stellar atmospheres of different metallicity

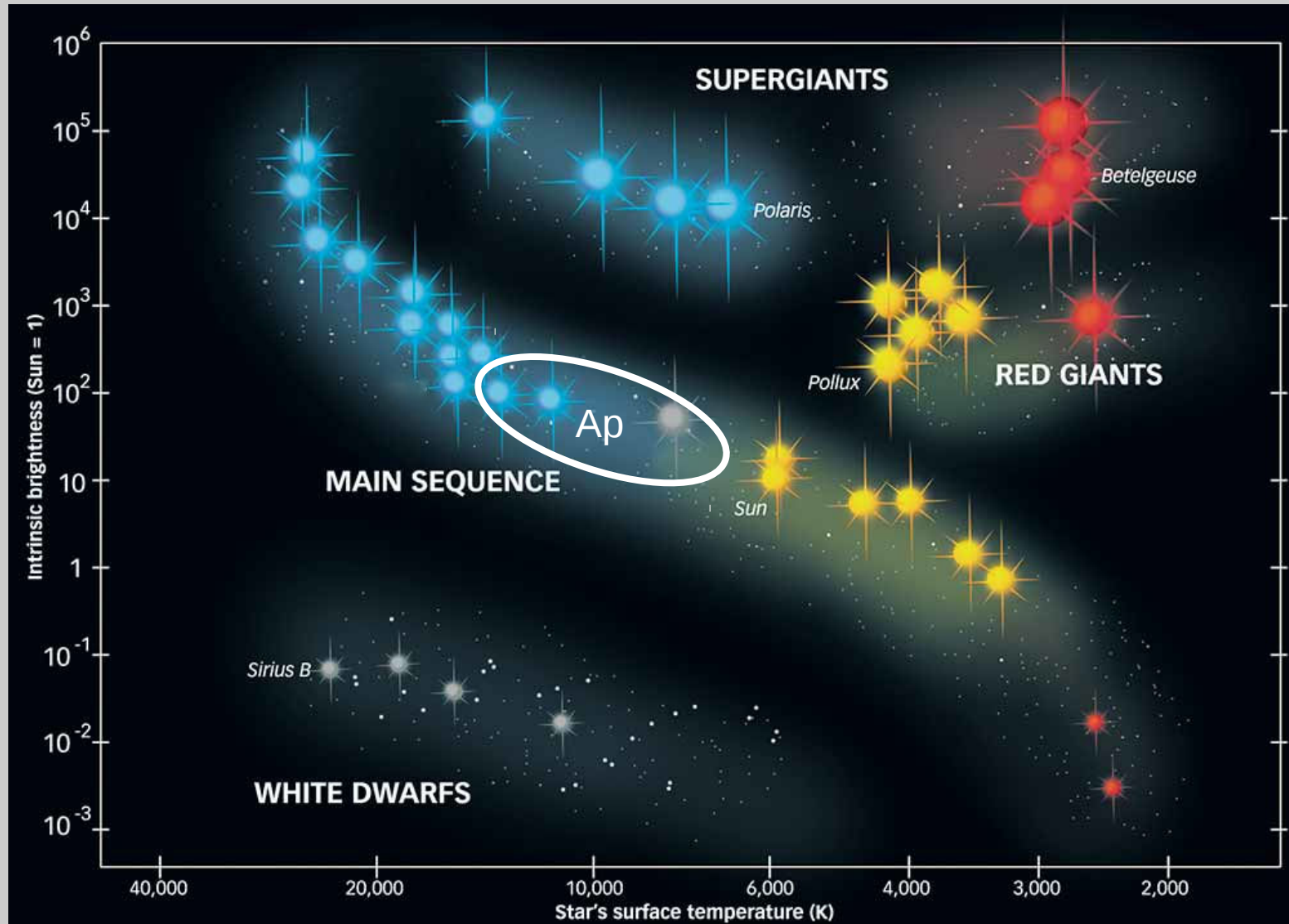


Data for HE 2327-562 are taken from Mashonkina et al. A&A 516, A46 (2010)

REEs in Galactic chemical evolution studies:

Fig.14 from Zhang et al. ApJ 509, id 225 (2016)

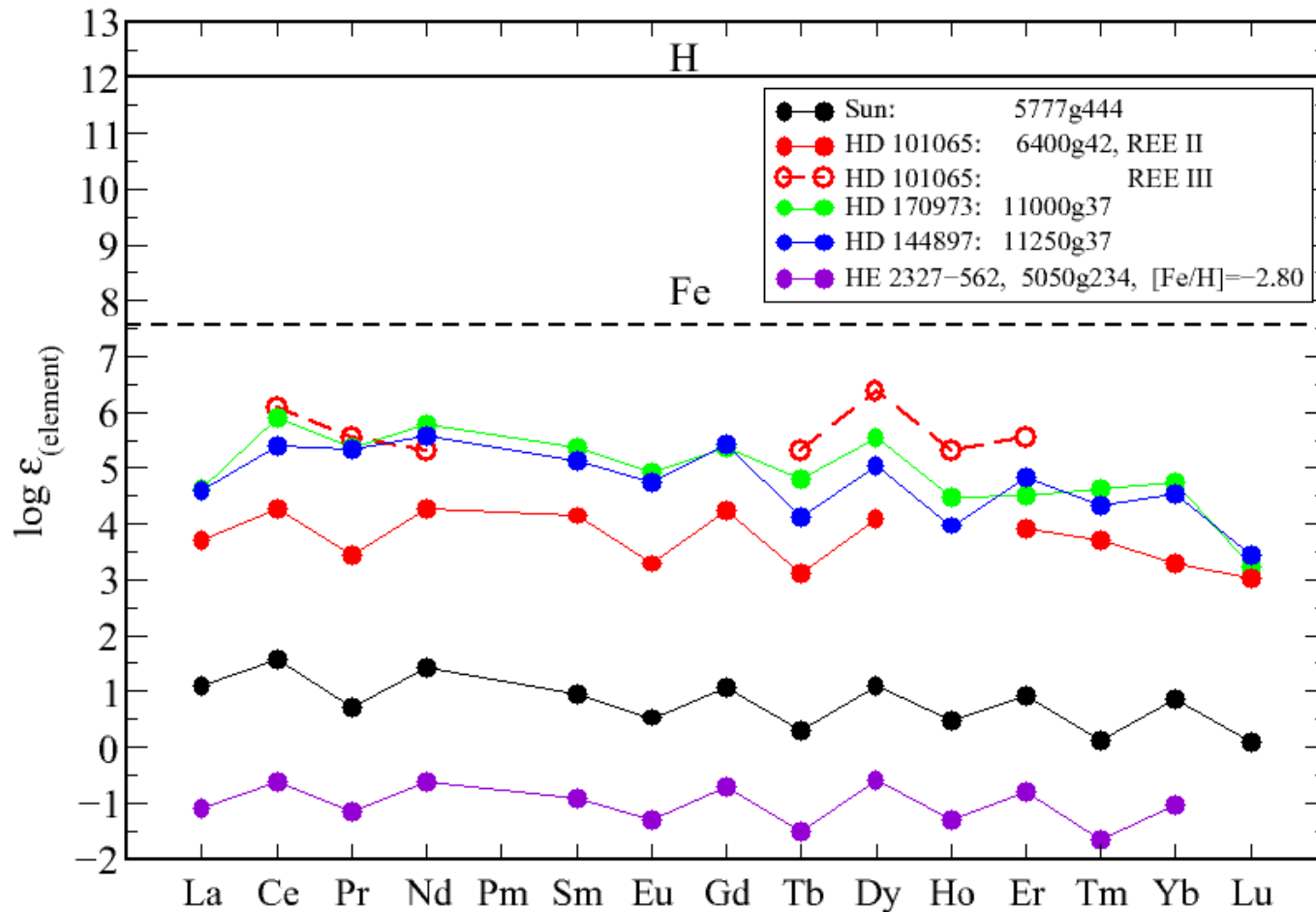




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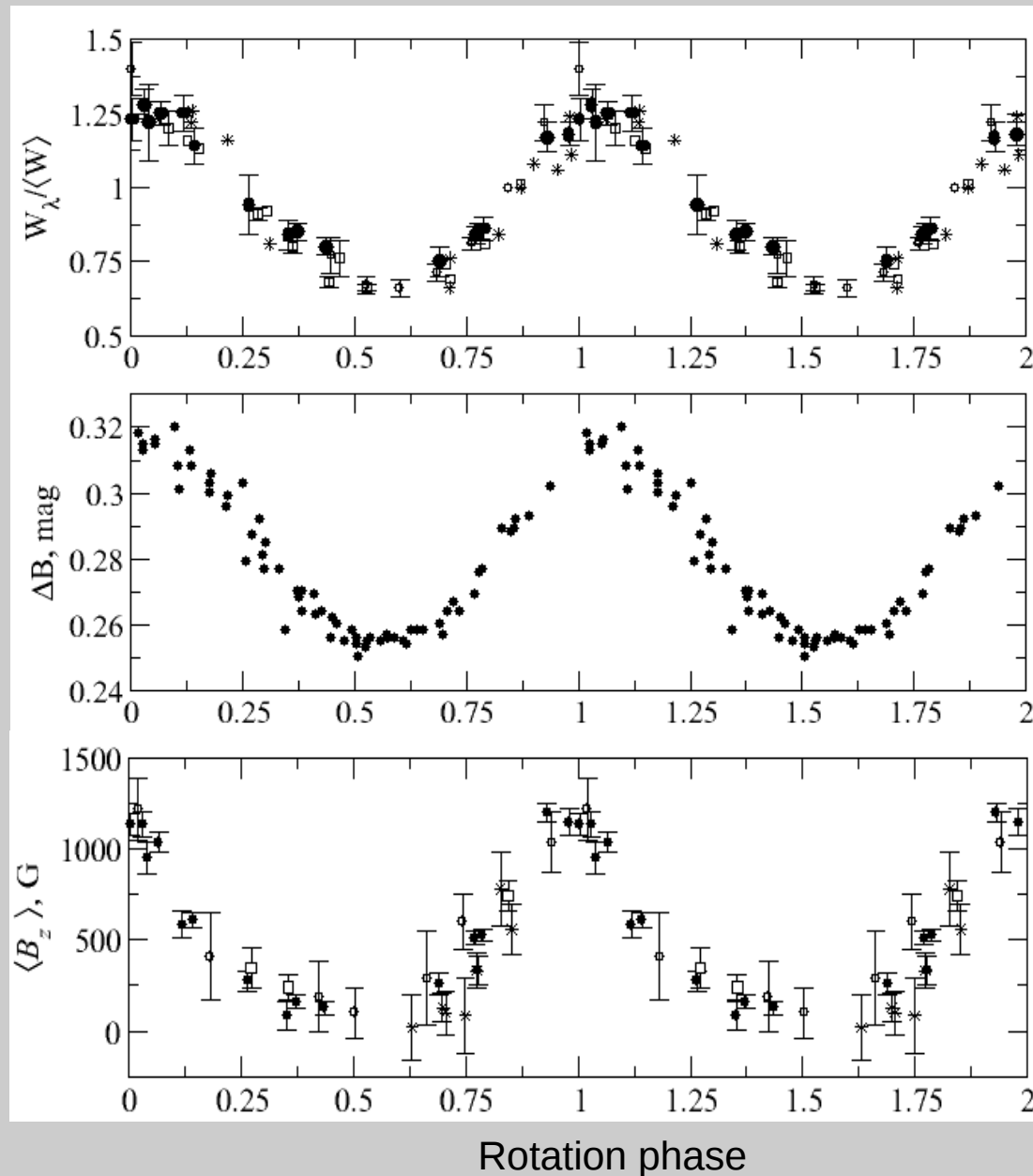
REE abundances in the atmospheres of magnetic chemically peculiar (Ap) stars

see also the poster S03-008
by A. Romanovskaya



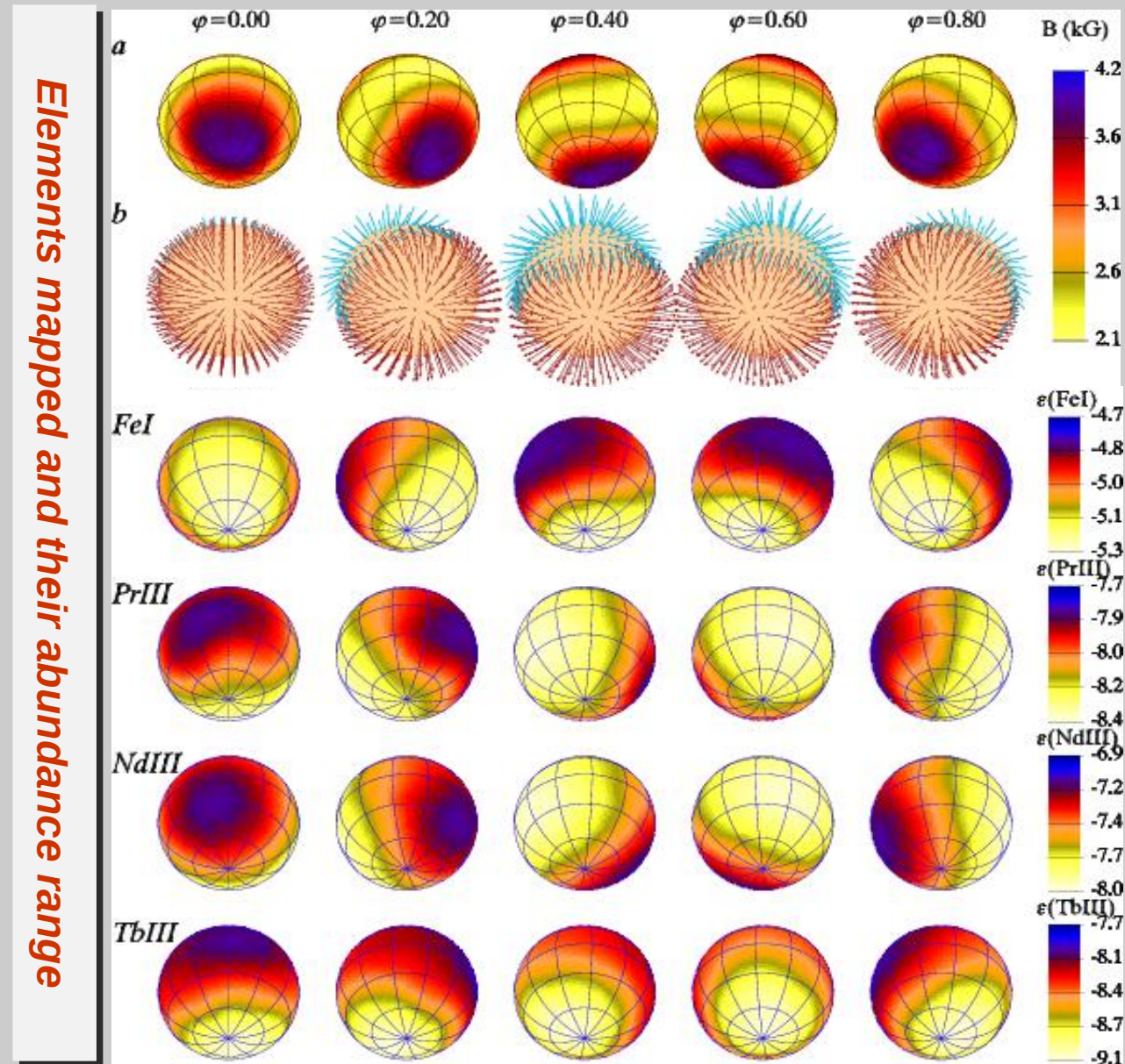
	Magn. field
HD 101065	2.3 kG
HD 170973	<1 kG
HD 144897	8.8 kG

Surface inhomogeneity: Periodic variations of the REE lines intensity. Oblique rotator model of Ap stars.



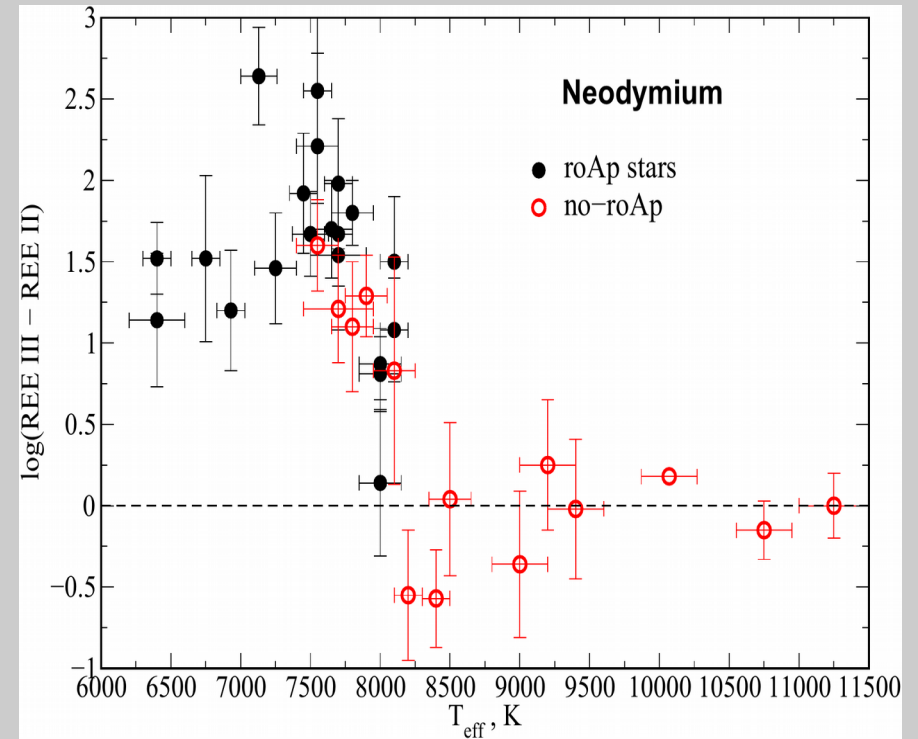
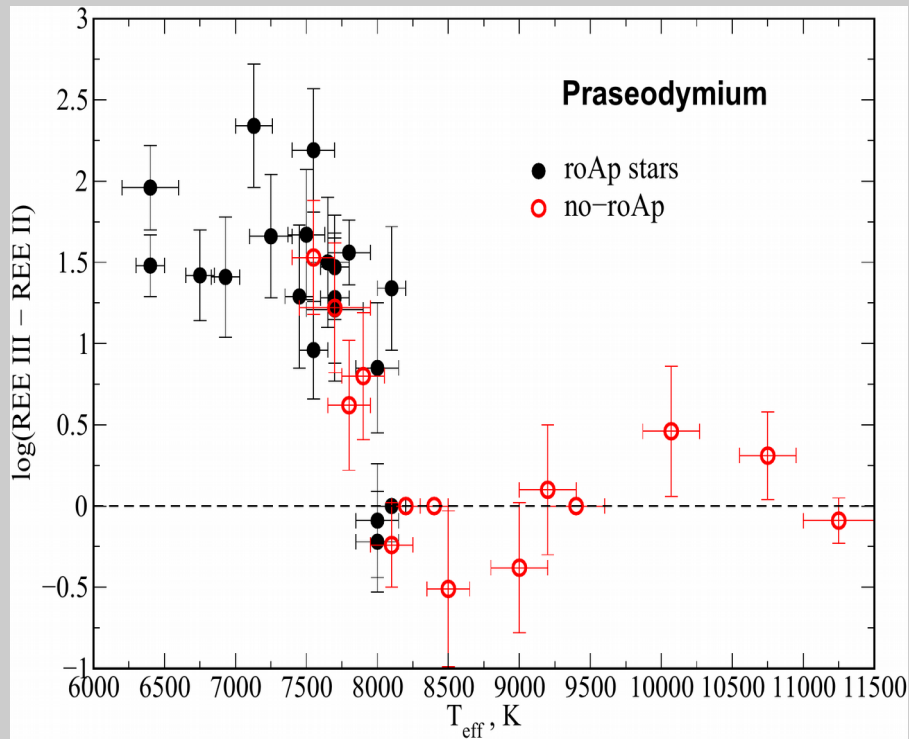
Surface distribution of the magnetic field, Fe and REE abundances in Ap stars:

The dipolar field of HD 24712



From Luftinger et al.
A&A 509, A71 (2010)

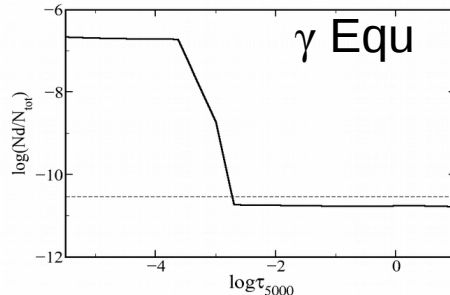
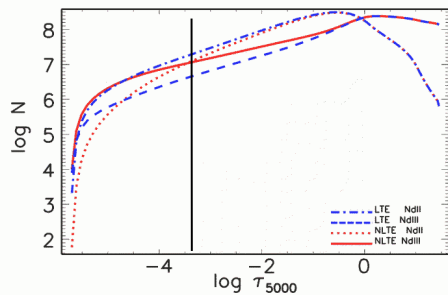
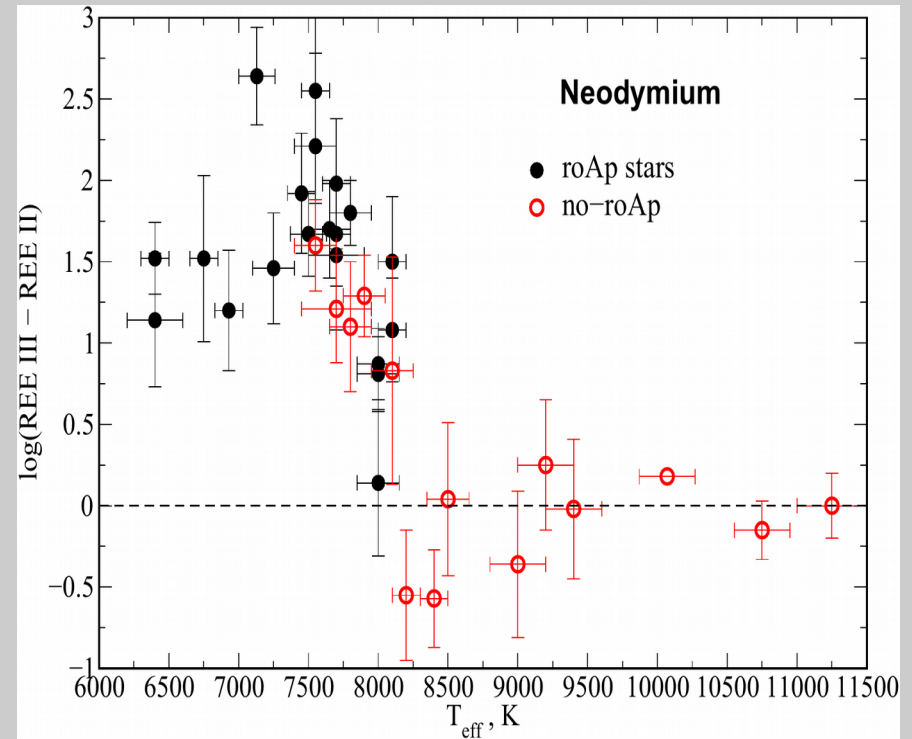
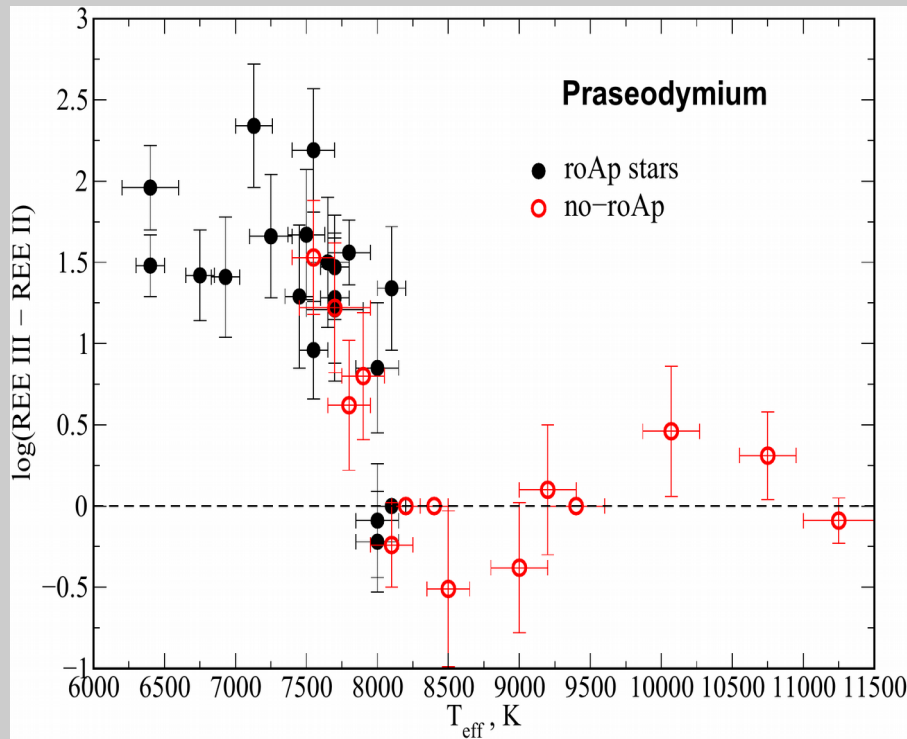
Vertical abundance gradients of the REE in Ap atmospheres: REE-anomaly



Ryabchikova et al. A&A 423, 705 (2004)

confirmed by Romanovskaya & Ryabchikova
Astr. Letters 43, 252 (2017)

Vertical abundance gradients of the REE in Ap atmospheres: REE-anomaly



Y-axis: Flux

X-axis: Wavelength (Å)

Label: Nd II 5319.820

Y-axis: Flux

X-axis: Wavelength (Å)

Label: Nd III 5294.110

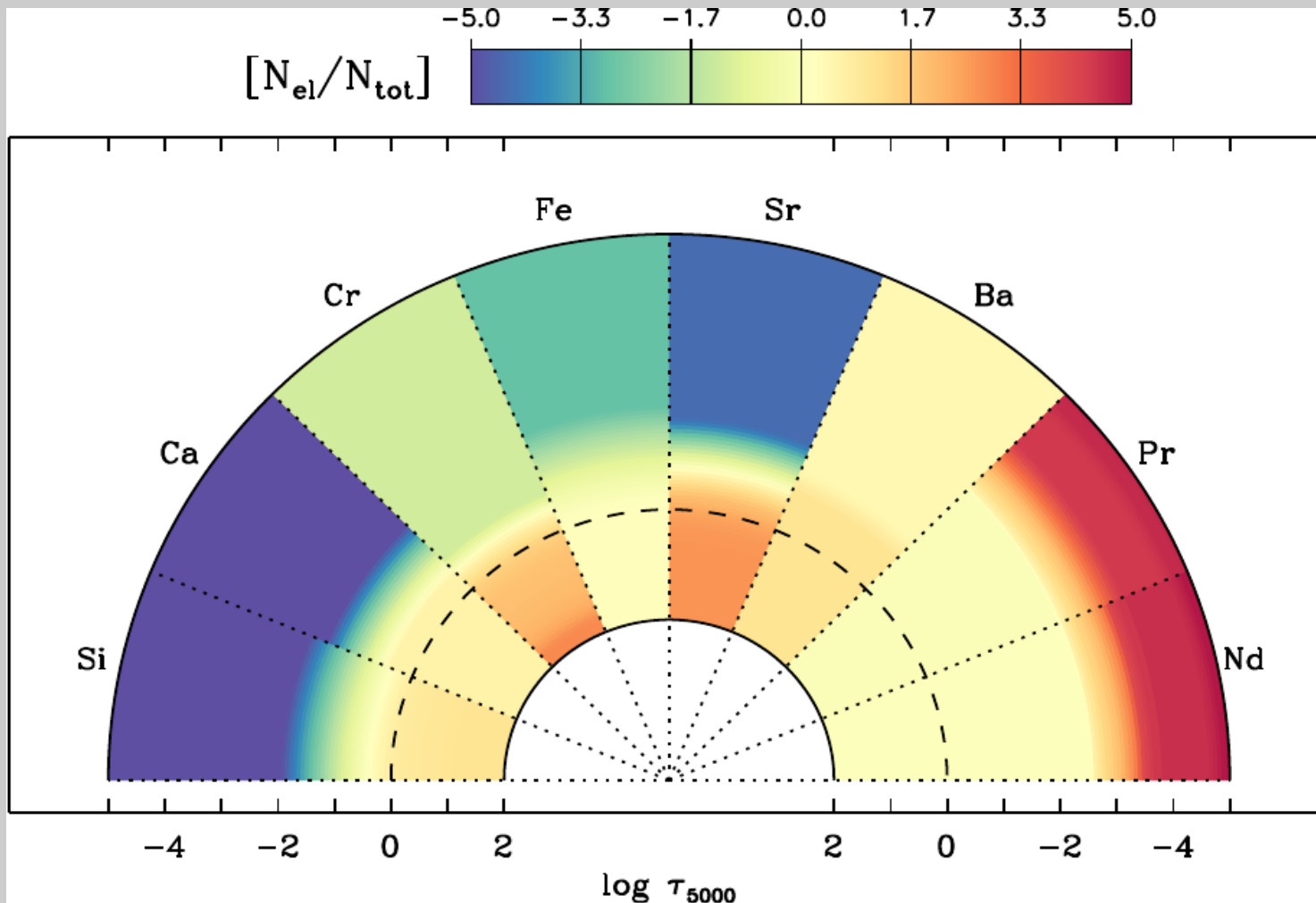
Ryabchikova et al. A&A 423, 705 (2004)

Empirical study of the REE stratification in Ap stars. Cases of Nd and Pr.

Mashonkina et al. A&A 441, 309 (2005) – Nd
Mashonkina et al. A&A 495, 297 (2009) – Pr

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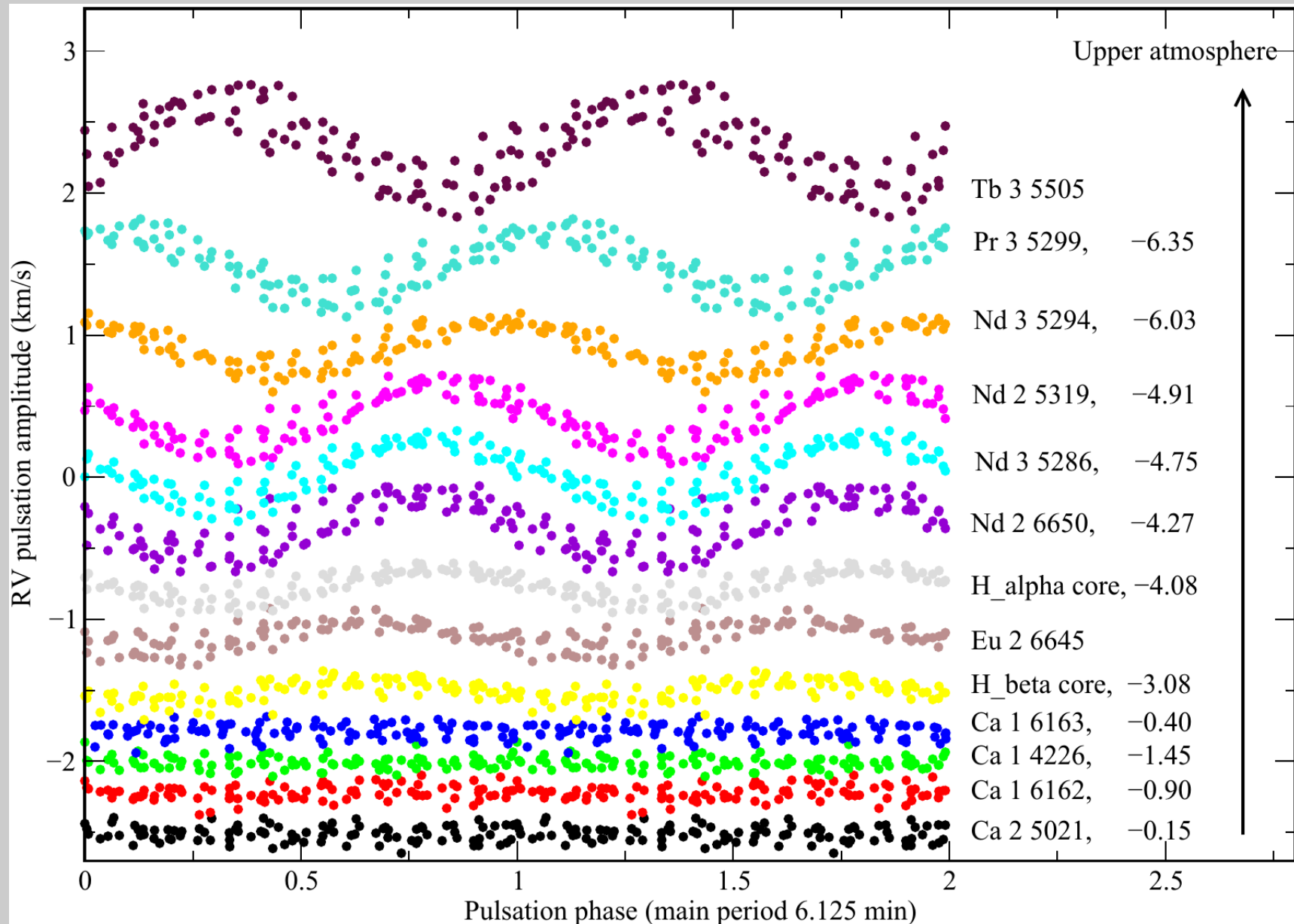
Schematic presentation of element abundance gradients
in the atmosphere of roAp star HD 24712 "layered cake"
(based on the results from Shulyak et al. A&A 499, 879, 2009)



Pulsations in the atmospheres of cool Ap (roAp) stars:

HD 24712 (Ryabchikova et al. A&A 462, 1103-1112, 2007)

running waves in roAp atmospheres

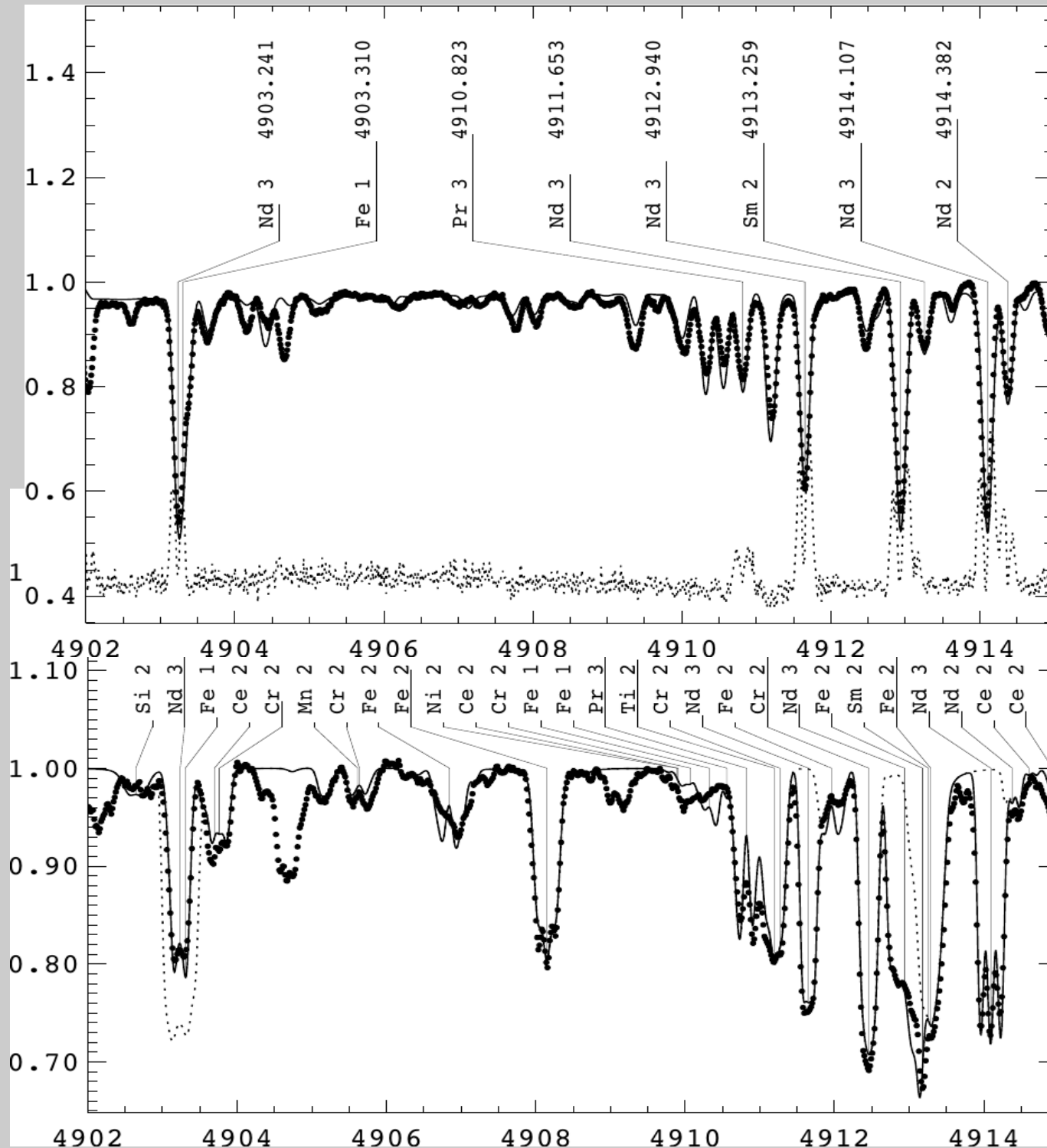


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Spectra of roAp-Ap stars
as a laboratory for REE
classification study.
(Ryabchikova et al. A&A
456, 329, 2006)

HD 24712
(roAp)
 $B_s = 2.3$ kG

HD 144897
 $B_s = 8.8$ kG



***Thank you for your
attention !***