Search for fine-structure constant variation in Ni II

Elena A. Konovalova

Petersburg Nuclear Physics Institute
Gatchina

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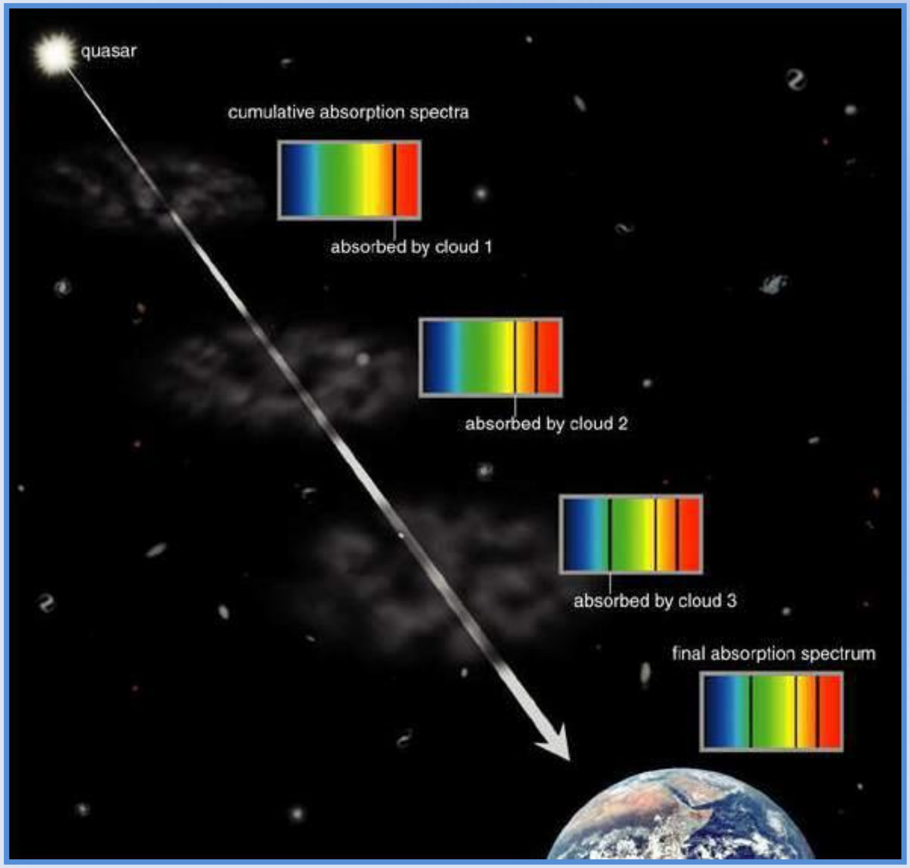
Fine-structure constant variation

Absorption lines of Ni II spectrum are observed by astrophysicists in quasar QSO SDSS J 081634+144612 (R.Guimaraes et al., 2012).



The spectra of atoms and ions are used to identify star composition and to search for fundamental constant variations.

Spectroscopy is a test ground to probe temporal and spatial variations.

Method

1. To calculate spectrum of Ni II we used the configuration interaction method (CI-method) for the Dirac-Coulomb Hamiltonian in no-pair approximation:

- We describe electronic structure of the ion in terms of frozen core approximation;
- The corrections of valence-valence correlations are taken into account;
- Then we find the energy levels and the wave functions of the ion;
- The different atomic properties are calculated (E1-amplitude, *g*-factors and *q*-factors).

Expansion of transition frequency in α

2. To determine the coefficients of sensitivity to α-variation:

$$\omega_i = \omega_i^{(0)} + \omega_i^{(2)} \alpha^2 + \ldots = \omega_{i,\mathrm{lab}} + q_i x + \ldots,$$
$$\omega_{i,\mathrm{lab}} = \omega_i^{(0)} + \omega_i^{(2)} \alpha_0^2,$$
$$x = (\alpha/\alpha_0)^2 - 1, \quad q = \partial\omega/\partial x\Big|_{x=0},$$

In order to detect α–variation we compare two transition frequencies:

$$\frac{\omega_i}{\omega_k} = \frac{\omega_i^{(0)}}{\omega_k^{(0)}} + \left(\frac{\omega_i^{(2)} - \omega_k^{(2)}}{\omega_k^{(0)}} \right) \alpha^2 + O(\alpha^4)$$

To calculate the relativistic energy shifts (q-factors) numerically we use:

$$q \approx \frac{\omega(x_+) - \omega(x_-)}{x_+ - x_-}$$

Results

State		Experiment		Theory		*q*-factor	
		ω	g	ω	g_{calc}	[1]	[2]
$^{4}D_{7/2}$		51558	1.420	49002	1.423	-2490(150)	-2415
$^{4}D_{5/2}$		52739	1.365	50239	1.359	-1290(150)	-1231
$^{4}D^{3}{}_{/2}$		53635	1.186	51183	1.187	-310(150)	
$^{4}G_{7/2}$		54263	1.025	51693	1.010	-1390(150)	-1361
$^{4}G_{5/2}$		55019	0.616	52482	0.609	-470(150)	-394
$^{4}F_{7/2}$		55418	1.184	53008	1.194	-1180(150)	-1114
$^{4}F_{5/2}$		56075	0.985	53728	0.996	-410(150)	-333
$^{2}G_{7/2}$	A	56371*	0.940	53972	0.923	-250(300)	-124
$^{4}F_{3/2}$		56425	0.412	54140	0.420	-140(150)	
$^{2}F_{7/2}$	B	57081*	1.154	54817	1.134	-790(300)	-700(250)
$^{2}D_{5/2}$	C	57420*	1.116	55315	1.100	-1500(150)	-1400(250)
$^{2}F_{5/2}$	D	58493*	0.946	56376	0.966	-100(150)	-20(250)
$^{2}D_{3/2}$		58706*	0.795	56770	0.799	-370(150)	
$^{4}P_{5/2}$		66571*	1.480	66169	1.506	-2210(150)	
$^{4}P_{3/2}$	E	66580	1.550	66173	1.592	-2290(250)	
$^{2}F_{5/2}$		67695	0.960	67512	0.943	-1900(150)	
$^{2}F_{7/2}$	G	68131*	1.200	67921	1.186	-1600(200)	
$^{2}D_{3/2}$	F	68154*	1.020	68080	1.033	-1090(250)	
$^{2}D_{5/2}$		68736*	1.264	68753	1.242	-410(150)	
$^{4}D_{7/2}$	H	70778	1.385	70704	1.383	-750(200)	

[1] Konovalova et al., PRA **90**, 042512 (2014); [2] Dzuba et al., PRA **66**, 022501 (2002).

The pairs of interacting levels

State		Experiment		Theory		*q*-factor	
		ω	*g*	*ω*	g_{calc}	[1]	[2]
$^2G_{7/2}$	A	56371*	0.940	53972	0.923	-250(300)	-124
$^2F_{7/2}$	B	57081*	1.154	54817	1.134	-790(300)	-700(250)
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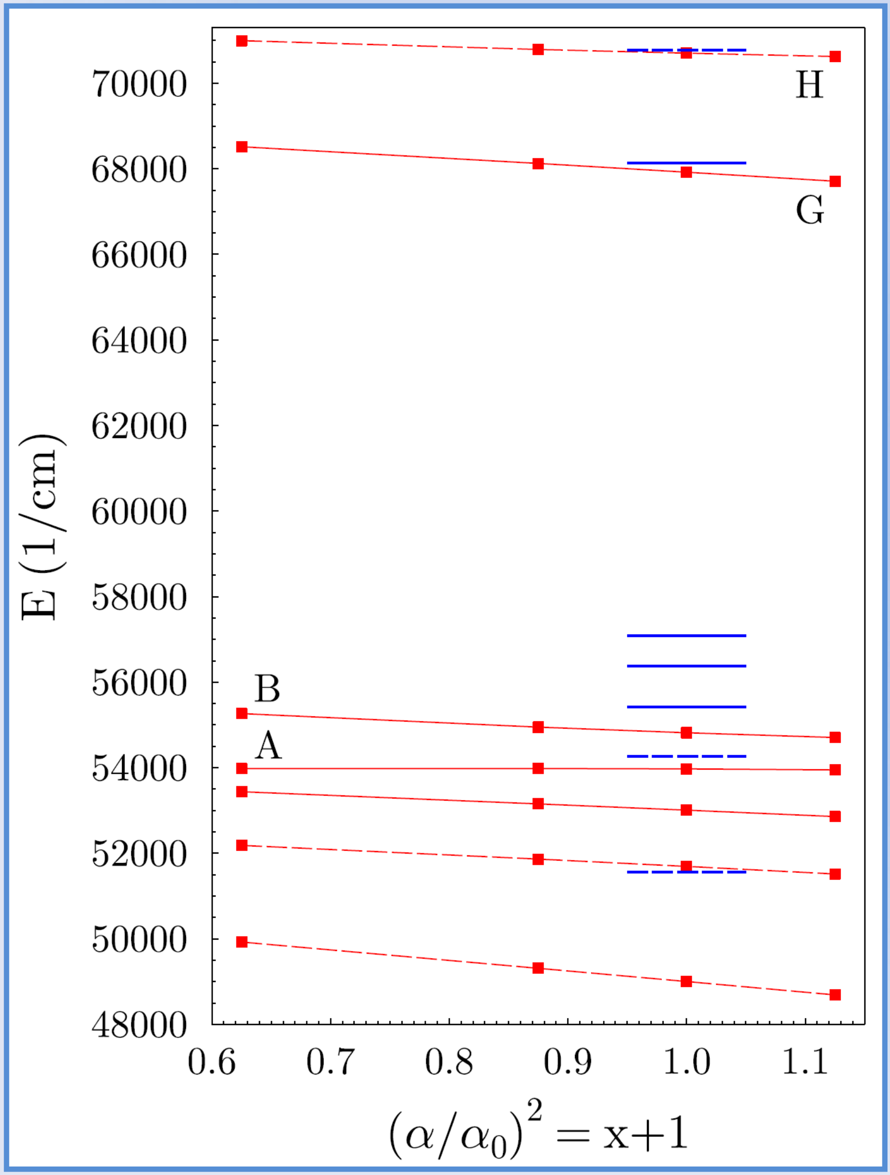
Sensitivity coefficients



– the dependence of the transition frequencies from the ground state on the parameter $(\alpha/\alpha_0)^2$.

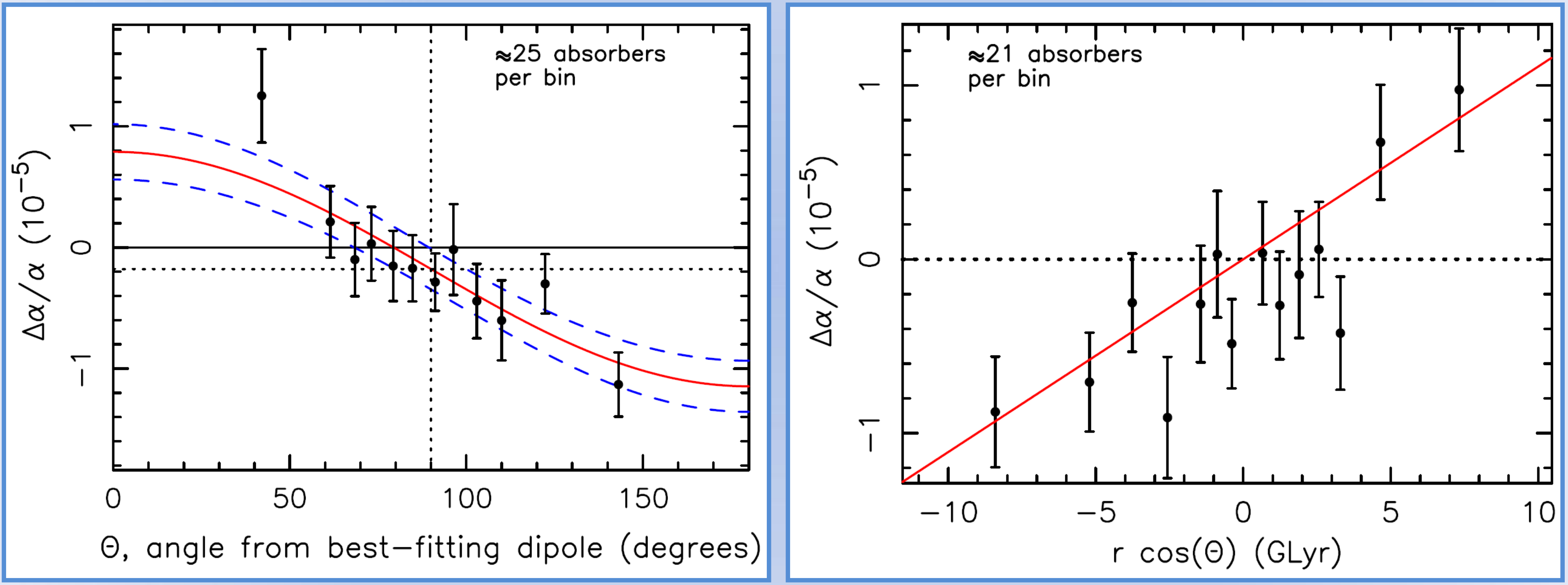
The large difference in sensitivities of individual lines increases sensitivity of the observations to α-variation.

Oscillator strengths

State		f_{osc}			
	ω (cm⁻¹)	*L gauge*	*V gauge*	Ref. [1]	Ref. [2]
$^4D_{7/2}$	51558	2.99×10^{-8}	9.83×10^{-11}		
$^4F_{7/2}$	55418	3.55×10^{-3}	3.55×10^{-3}	7.16×10^{-3}	
$^4F_{5/2}$	56075	5.39×10^{-4}	5.33×10^{-4}		
$^2G_{7/2}$	56371*	2.22×10^{-3}	1.95×10^{-3}	6.22×10^{-3}	
$^4F_{3/2}$	56425	6.13×10^{-5}	6.92×10^{-5}		
$^2F_{7/2}$	57081*	2.75×10^{-2}	2.53×10^{-2}	2.77×10^{-2}	2.77×10^{-2}
$^2D_{5/2}$	57420*	5.05×10^{-2}	5.03×10^{-2}	4.27×10^{-2}	4.27×10^{-2}
$^2F_{5/2}$	58493*	4.50×10^{-2}	4.36×10^{-2}	3.24×10^{-2}	3.24×10^{-2}
$^2D_{3/2}$	58706*	1.04×10^{-2}	1.06×10^{-2}	6.00×10^{-3}	6.00×10^{-3}
$^4P_{5/2}$	66571*	5.24×10^{-3}	4.76×10^{-3}	6.00×10^{-3}	
$^4P_{3/2}$	66580	4.40×10^{-4}	3.12×10^{-4}		
$^2F_{5/2}$	67695	6.94×10^{-4}	8.64×10^{-4}		9.72×10^{-4}
$^2F_{7/2}$	68131*	1.02×10^{-2}	1.20×10^{-2}	9.90×10^{-3}	9.90×10^{-3}
$^2D_{3/2}$	68154*	8.87×10^{-3}	8.03×10^{-3}	6.30×10^{-3}	6.30×10^{-3}
$^2D_{5/2}$	68736*	3.03×10^{-2}	2.87×10^{-2}	2.76×10^{-2}	3.23×10^{-2}
$^4D_{7/2}$	70778	3.15×10^{-3}	3.59×10^{-3}		

[1] H.Rahmani and R.Srianand (private letters), 2014; [2] D.C.Morton, ApJS**149**, 205, 2003.

Australian dipole



(Webb et. al, PRL, **107**, 191101 , 2011)

The evaluation of systematic errors are given in:
Whitmore J.B. and Murphy M.T., arXiv:1409.4467

Conclusion

1. We calculated the *q*-factors for several lines, which had not been studied theoretically before, but were observed in the high redshift quasar spectra.

2. All calculated sensitivities for astrophysically relevant transitions in Ni II are negative. Two of these lines have relatively small *q*-factors (≈ -400 cm^{-1}) and one has q factor, which is one of the largest in absolute value, $q = -2210$ cm^{-1}. The comparison of lines with widely varied *q*-factors allows obtaining information concerning α–variation.

3. The present accuracy of our calculations is sufficient to analyze astrophysical data on the possible fine-structure constant variation.

Thank you for your attention!