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Spectral lines in the afterglow of Gamma Ray Bursts

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- Basics of GRB phenomena
  - GRBs are random flashes in gamma rays.
  - Discovered at the end of 60s by Vela military satellites and publicly announced 1973. (Klebesadel, 1973).
  - They have cosmological origin, what has been discovered and confirmed by BATSE on CGRO satellite.
  - They are high energy phenomena with $E=(10^{51}-10^{53})ergs$
  - After initial gamma radiation there is lower energy follow-up, in form of X-rays, optical and radio emission. It has been discovered by the BeppoSAX satellite in 1997. (Costa, et al., 1997; van Paradijs, et al., 1997; Frail, et al. 1997).
  - The basic classification is according to duration of gamma phase, in short (T_{90} < 2s) and long (T_{90} > 2s) GRBs.

Klebesadel, R. W., Strong, I. B., Olson, R. A., Ap. J., 182, (1973), L85.
Costa, E., Frontera, F., Heise, J., et al., Nature, 387, (1997), 783.
van Paradijs, J., Groot, P. J., Galama, T., et al., Nature, 386, (1997), 686.
Frail, D. A., Kulkarni, S. R., Nicastro, S. R., et al., Nature, 389, (1997), 261.

- Currently employed model
  - Although there is no overall accepted model the parts of structure has been theoretically threated with sufficient agreement with observation.
  - Fireball model consider ultra-relativistic expansion of the ejected material.
  - In the first phase GRB core generate small shock waves. Their mutual interaction produce light curve variability (Simić, 2004; Simić, et al., 2007).
  - In the second phase (afterglow phase) massive shock wave is generated which produce the radiation on the lower energy (x-ray, optical and radio).
  - Radiation emerging from the shock wave travel through the sourounding media, which than leave the foot prints in the form of the spectral lines.

Simić, S. Baltic Astronomy, 13, (2004), 297.
Simić, S., Popović, L. Č., Andersen, M. I. and Christensen, L., A&SS, (2007) in press

- Model of GRB progenitors
  - The progenitors and sites of GRBs are still unknown.
  - Merging of two compact objects like neutron star binary or neutron star and black hole in the baryon-clean environment was a popular scenario at the time when GRB afterglows were discovered.
  - However, observations appear to suggest that more “dirty” circumstances are in place of events, confirming by that the hypernova (Paczynski 1998), collapsar (Woosley 1993), or supranova scenarios (Vietri & Stella 1998).

Paczynski, B., ApJ, 494, (1998), L453.
Woosley, S. E., ApJ, 405, (1993), 2739.
Vietri, M. & Stella, L., ApJ, 507, (1998), L45L.

- Typical spectral lines observed in the GRBs

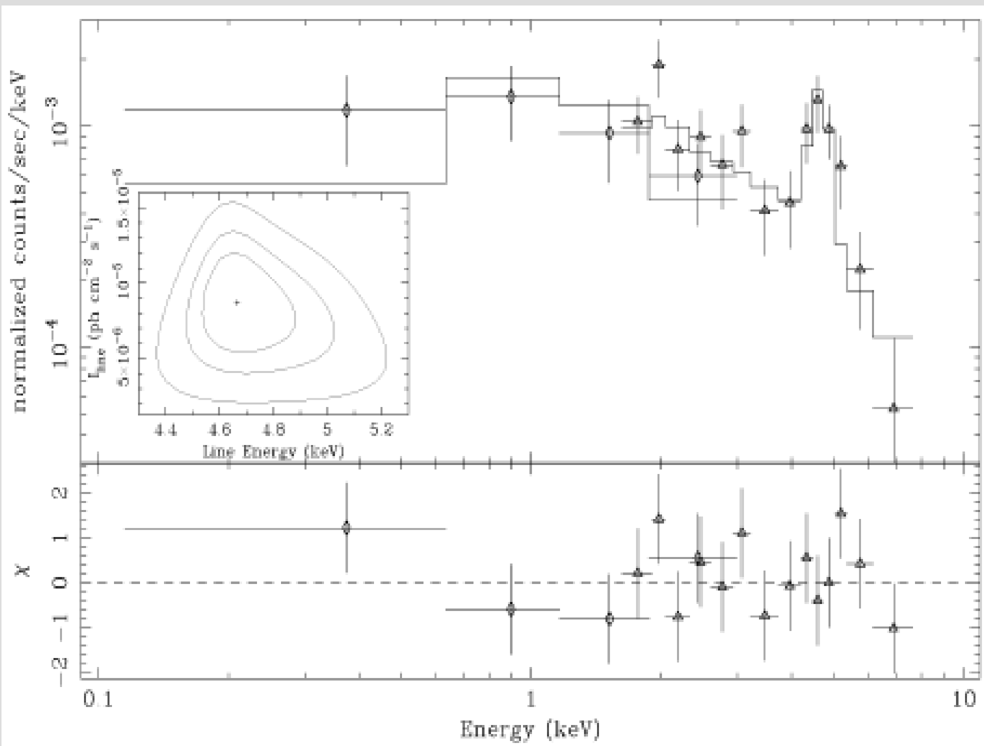

Fig1. BeppoSAX (0.1–10.0 keV) spectra of GRB000214 X-ray afterglow. Iron Kα line is clearly visible in LECS + MECS spectra fitted with an absorbed power law plus a narrow Gaussian line. The inset show the contour plot of the line intensity vs. energy. (Antonnelli, et al 2000).

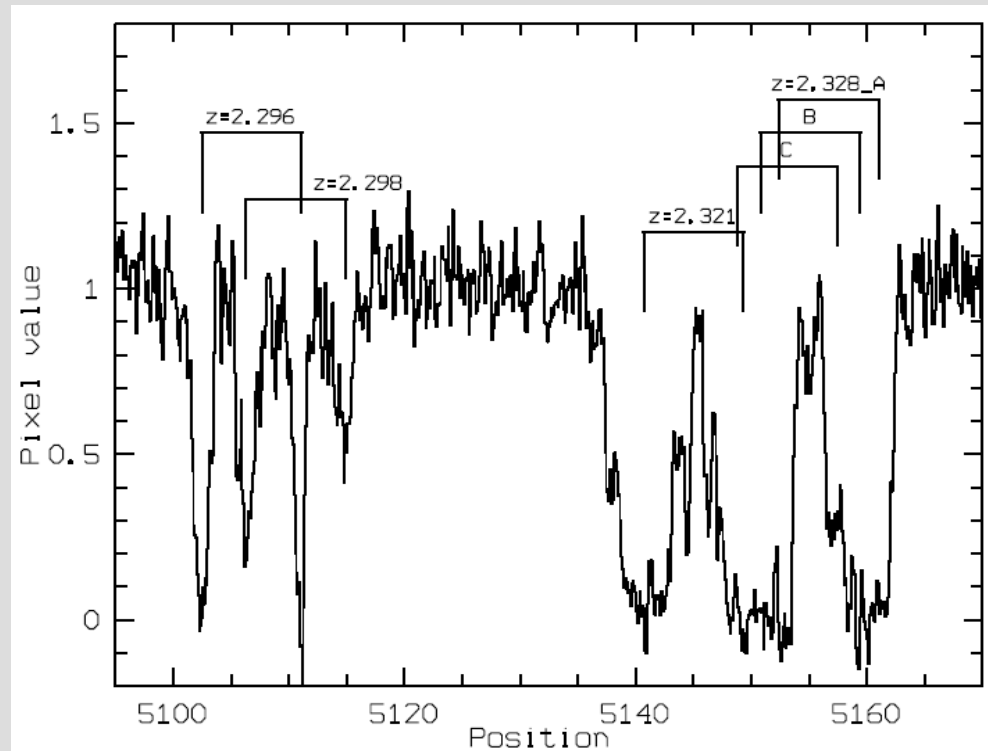

Fig2. C IV absorption systems in the UVES (Ultraviolet and Visual Echelle Spectrograph) spectra of GRB021004 for z=2.328. (Ward, et al. 2005).

Antonelli, L. A., Piro, L., Vietri, M., et al., ApJ, 545, (2000), L39.
Ward, P., Meurs, E. J. A., Fiore, F., et al., NcimC, 28, (2005), 783W.

- Exploring the ISM using GRBs
  - An alternative approach for probing intervening gas in galaxies and the IGM is to use the afterglows of gamma-ray bursts (GRBs). In the context of the relation to star formation and the nature of DLAs, GRBs offer several advantages over quasar studies.
  - GRBs are embedded in star forming galaxies with typical offsets of a few kpc or less (Bloom, 2002). They therefore probe the regions of most intense star formation, and hence production and dispersal of metals.
  - Since the GRB afterglow emission fades away on a timescale of days to weeks, the host galaxy can be subsequently studied directly (Vreeswijk, 2004).
  - Since GRBs are likely to be located in star forming regions (e.g., molecular clouds) within their host galaxies, this approach provides the only systematic way to directly probe the small-scale environment and conditions of star formation at high redshift.

Bloom, J. S., Kulkarni, S. R. and Djorgovski, S. G., AJ, 123, (2002), 1111.
Vreeswijk, P. M., Ellison, S. L., Ledoux, C., et al., A&A, 419, (2004), 927.

- Description of method used
  - The goal is to statisticaly investigate the abundances in surroundings of sample of GRB events by using the COG (Curve Of Growth).
  - Since most of the lines are saturated and therefore do not lie on the linear part of the curve of growth we construct a joint COG for all the detected transitions.
  - In this case we use the standard formulation (Spitzer, 1978):

$$W_{\lambda}=\frac{2bF(\tau_0)\lambda}{c}$$

$$\tau_0=\frac{\pi^{1/2}e^2 f\lambda N}{m_e c b}=1.496\cdot 10^{-15}\frac{f(\lambda/\overset{o}{A})N}{(b/km\,s^{-1})}$$

$$F(\tau_0)=\int_0^{\infty}\left[1-\exp\left(-\tau_0 e^{-x^2}\right)\right]dx$$

Spitzer, L. 1978, Physical Processes in the InterstellarMedium (New York: Wiley)

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- Fitting process:
  - The best-fitting column density is determined by using simultaneously different EWs of various ions and choosing the COG with an effective Doppler parameter that minimizes the χ^2.

Fe II	GRB030926	GRB010222
λ [Å]	W_λ [Å]	
1608	0.64	0.47
2260	-	0.52
2344	1.40	1.92
2374	0.79	1.60
2382	1.83	2.35
2586	1.37	1.53
2600	1.93	2.31

Table 1. Equivalent widths for two GRBs from the sample, for FeII ion.

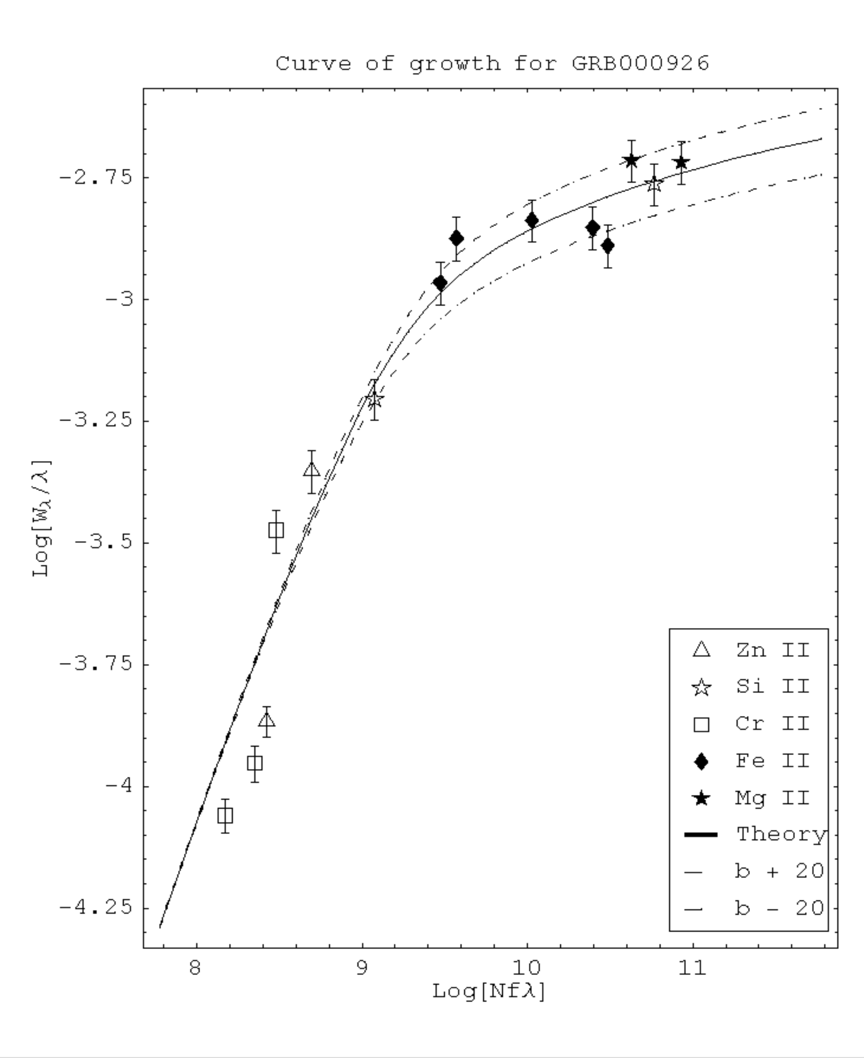

Fig 3. COG for GRB000926 absorption lines. Parameter b is derived in the fitting process and has a value b = 120.

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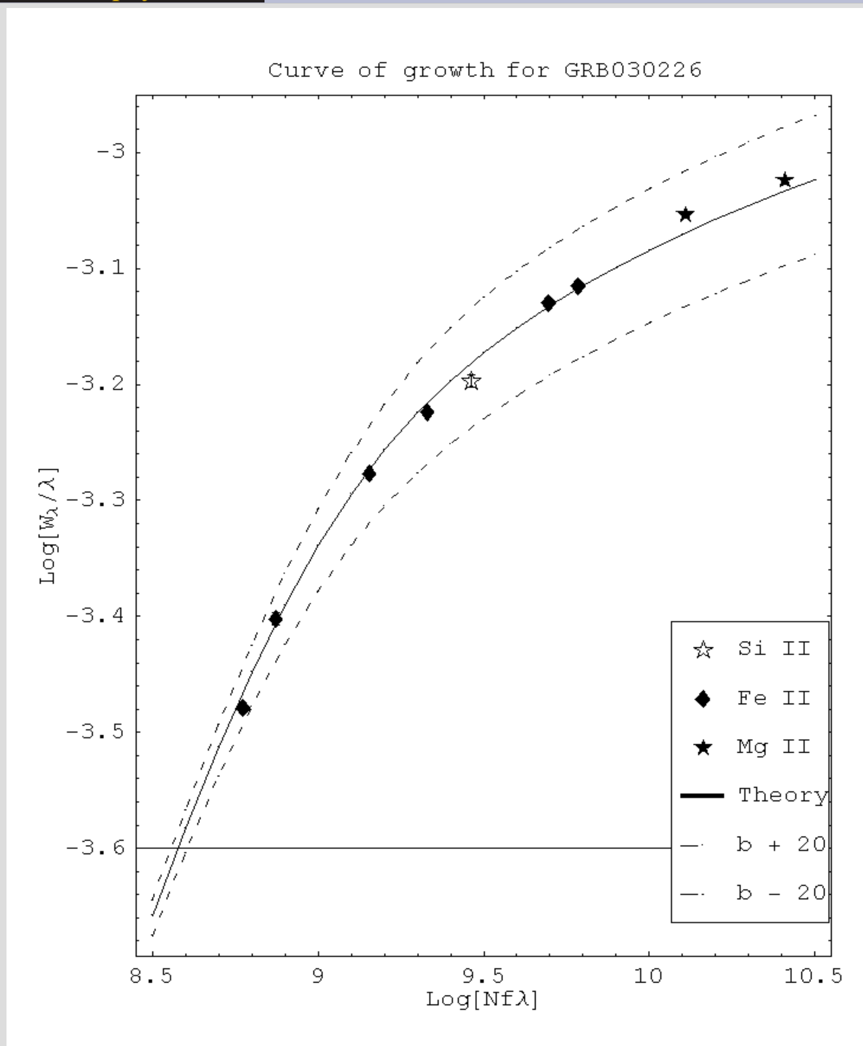

Fig 4. Same as in Fig 3. but for the GRB030226. Parameter b has a value b = 65.

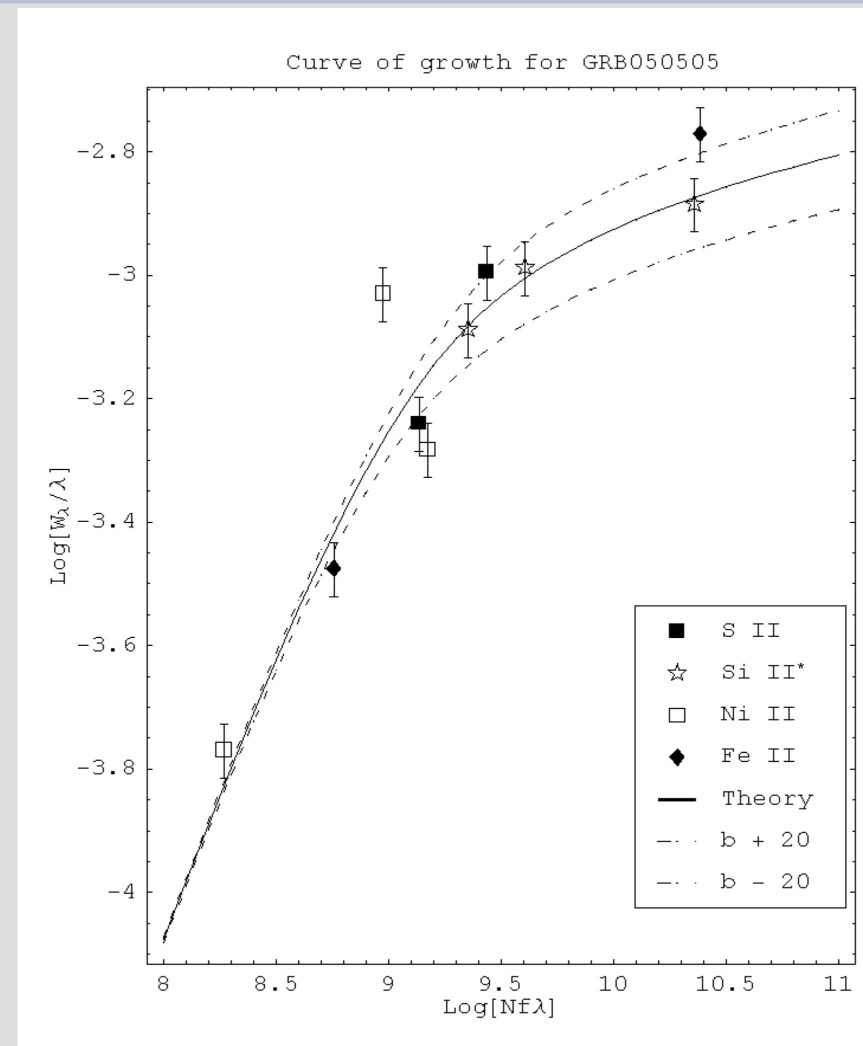

Fig 5. Same as in Fig 3. but for the GRB050505. Parameter b has a value b = 100.

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Table 2. Results of COG fitting for eight different GRBs.

GRB event	Al II	Zn II	Si II	Cr II	Mg II	Mn II	Fe II	NI II	b [km/s]
GRB990123	-	14.00	-	-	-	-	15.23	-	40
GRB000926	-	13.67	16.47	14.14	15.69	-	16.60	-	120
GRB010222	-	13.77	16.14	15.30	-	13.69	15.30	-	70
GRB011211	13.77	-	15.39	-	-	-	14.54	-	90
GRB020813	-	-	-	-	13.23	-	15.69	-	50
GRB030226	13.00	-	15.17	-	15.17	-	14.90	-	65
GRB050505	-	-	15.14	-	-	-	16.41	15.30	100
GRB051111	-	13.47	16.20	13.81	14.84	13.39	15.14	14.13	12

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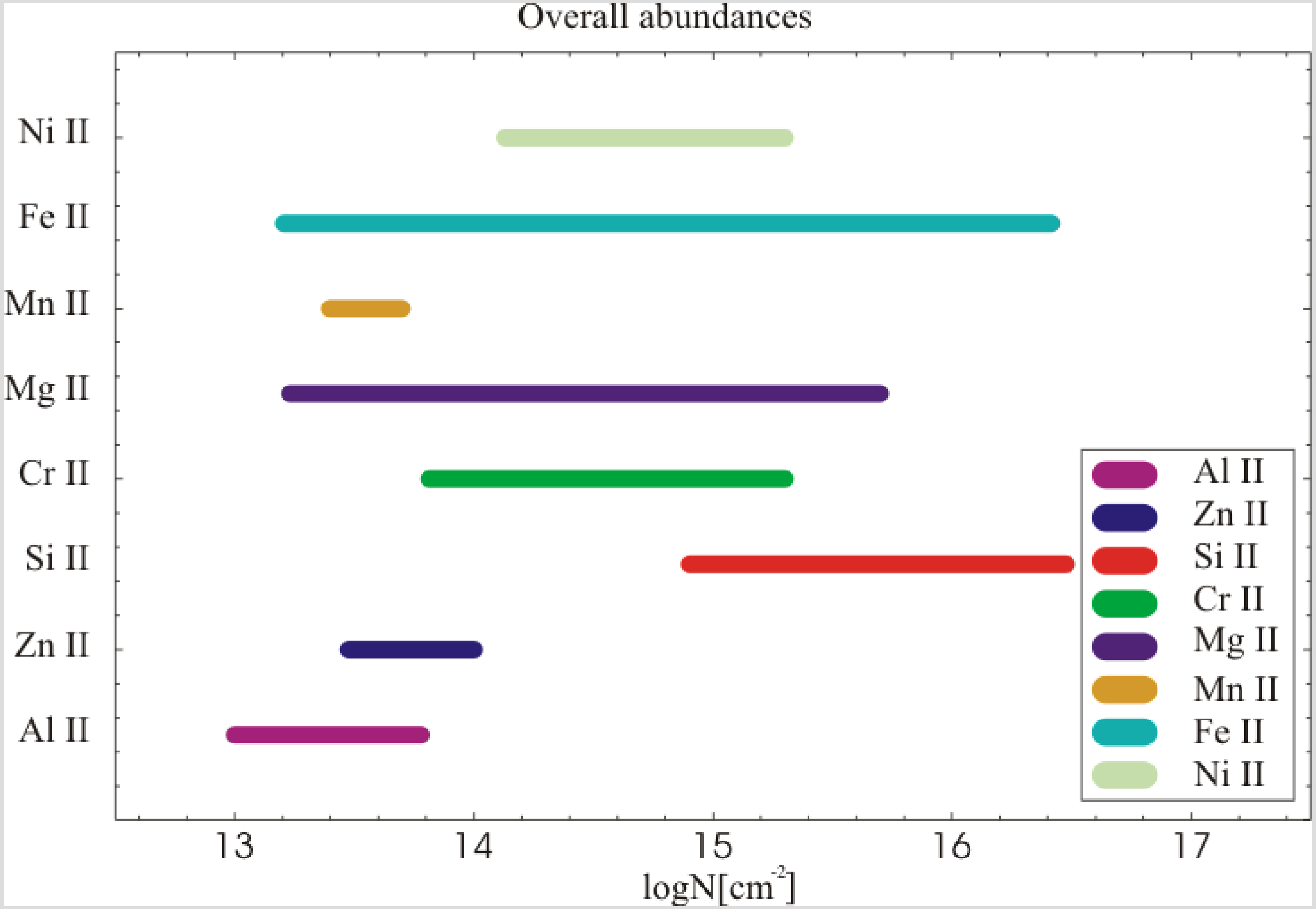

Fig 6. Graphics of abundance.

Thank you!