Clustering of galaxies around the GRB 021004 sight-line at z ~ 0.5

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Abstract In this report we test for reliability any signatures of field galaxies clustering in the GRB 021004 line of sight. The first signature is the BTA and Hubble GRB 021004 field photometric redshift distribution with a peak at z ~ 0.5 estimated from multicolor photometry. The second signature is the MgII 2796,2803 absorption doublet at z ~ 0.5 in the GRB 021004 afterglow spectrum. The third signature is some inhomogeneity in Plank + GRB 021004 fields. And the fourth signature may be the galaxy clustering with an effective redshift of z = 0.5 from the Baryon Oscillation Spectroscopic Survey (BOSS), which is a part of the Sloan Digital Sky Survey III (SDSS-III).

Keywords: Galaxy Clustering, Gamma-Ray Bursts, Multicolor Photometry

1. Introduction. Clustering of galaxies and quark phase transition in compact objects: neutrino, supernovae and gamma-ray bursts

As is well known, measurements of the surface brightness of galaxy clusters can be used to estimate the angular diameter and distance to these structures [1]. Namely, the determination of distance to sources of neutrino signals, supernovas and gamma-ray bursts resulting from quark transitions in compact objects becomes the main observational task in determining the basic parameter – an energy release related to sources of such events.

On the other hand, it is known that distribution of such sources over the sky can be anisotropic. Now this can be said with confidence at least about GRBs whose distribution correlates with nonuniformities of distribution of the cosmic microwave background (CMB) signals [2]. Paper [3] also says about anomalies in the GRB spatial distribution. A discussion on a possible clustering of neutrino signals in relation with GRBs can be seen in [4]. Observational determination of such relations directly influences the study of neutrino signals, GRBs and supernovae.

There is a mysterious connection between Gamma-Ray Bursts (GRBs) and core collapse supernovae (SNe). At least, long-duration GRBs are associated with the core collapse of very massive stars ([5] – [8]). Similarly to core collapse SNe, the most probably, in GRBs also the collapse of massive stellar iron cores results in the formation of a compact object (collapsar), accompanied by the high-velocity ejection of a large fraction of a progenitor star mass. The collapse of the massive stellar core is connected with the quark phase transition in the compact objects, which leads to neutrino and photons signals from the core collapse SNe and GRBs.

On the other hand, the sky distribution of electromagnetic and neutrino signals associated with the core collapses can be non-isotropic [9], which can be related eventually with the clustering of galaxies in which the formation of compact objects occurs due to evolution of massive stars. The clustering of galaxies and the clustering around GRB sight-lines are detected and studied in the same manner employed with quasar spectroscopy in many papers already [10]. Galaxies that give rise to absorption line systems in gamma-ray bursts afterglow spectra have been directly imaged and investigated. So, it is possible to try to find the overdensity excess of GRB field galaxies around GRB positions by different methods – spectroscopic, photometric ones (deep images multiband photometry) plus the search for correlation with Cosmic Microwave Background (CMB) and others.

2. The Clustering of galaxies around GRB sight-lines

The Clustering of galaxies around GRB sight-lines are detected and studied in detail in many papers already since [10]. Gamma-ray Bursts (GRBs) originate at cosmological distances with energy releases of 10^{51} – 10^{53} ergs at a range of redshifts between ~0.01 and up to 10 [10]. Besides studying their host galaxies, prompt spectroscopy of the GRB afterglows has revealed (in the optical) intervening absorption systems as found in the past with quasar spectroscopy. One of such is Mg II (rest) 2800 A which is strong and ease to detect in moderate S/N spectra. Using a large sample of GRB afterglows, it has been found [11], [12] an overdensity (the factor 2–4) of strong Mg II absorption line systems along the lines of sight. If this excess of intervening systems is real, it should be possible to find an excess of GRB field galaxies around GRB positions, although a preliminary study has revealed no anomalous clustering of galaxies (in comparison with distribution of quasar?) at the estimated median redshift ~0.3 around GRB line of sights [10]. Furthermore, it has been proposed that the majority of short-duration GRBs in early-type galaxies will occur in clusters and three such relationships have been already found [13]. Though the paper authors [10] are interested mostly in the GRB/quasar overdensity excess of field galaxies around sight-lines, and, in connection with this problem they made a good review (for 2013) of spectroscopic data of the 73 GRB afterglows. Intervening absorption line systems for GRB afterglows can be detected in the same manner employed with quasar spectroscopy. One such absorption line system is MgII, which is easily detected in moderate S/N spectra at λ ~2800 (MgII 2796,2803 doublet). As strong MgII tends to trace these galaxies, we will proceed from these spectra in our photometric study of the field galaxies around GRB 021004 line of sight.

One of these fields GRB000926 (Table 1) was already investigated and the results were published [14]. This work presents the observations of a 3.6′ x 3′ field centered on the host galaxy of GRB000926 (J2000.0=$17^h04^m11^s$, J2000.0=+51°4′9.8″). The observations were carried out on the 6-m Special Astrophysical Observatory telescope using the SCORPIO instrument. The catalog of galaxies detected in this field includes 264 objects for which the signal-to-noise ratio is larger than 5 in each photometric band. The following limiting magnitudes in the catalog correspond to this limitation: 26.6(B), 25.7(V), 25.8(R_c), and 24.5(I_c). The differential galaxy counts are in good agreement with previously published CCD observations of deep fields. Authors estimated the photometric redshifts for all of the cataloged objects and studied the color variations of the galaxies with redshift. For luminous spiral galaxies with M(B) < 18, authors found no evidence for any noticeable evolution of their linear sizes to z~1.

BTA observation data are the base of our investigations. While studying other fields (Table 1) (GRB021004, GRB970508 + investigation of surroundings of radio-source RC J0311+0507), these data where supplemented with data obtained with other instruments. One of the goals of this work is to point out what is possible to obtain with 6-m telescope in these challenging and actual tasks, supplementing these studies with other instruments' data.

Table1. *BTA GRB deep fields*

GRB	Filters	FWHM	T_{exp}, sec
GRB970508	BVRI	1″.3	600×7, 500×4, 600×5, 400×5
GRB971214	VR	1″.2	600×1, 600×1
GRB980613	BVRI	1″.3	700×1, 600×1, 600×3
GRB980703	BVRI	1″.3	480×1, 320×1, 300×1, 360×1
GRB990123	BVRI	1″.5	600×1, 600×1, 600×1, 600×1
GRB991208	BVRI	2″.1	300×6, 300×5, 180×7, 180×2
GRB000926	BVRI	1″.3	500×5, 300×5, 180×25, 120×15
GRB021004	BVRI	1″.5	600×6, 450×13, 180×15, 120×14

3. Method of photometry of GRB 021004 and RC J0311+0507 fields

We used the GRB021004 field, which was obtained as a part of GRB afterglow observations program (see Table 1) [15]. This field has exposure times of about one hour in each of the BVRI optical bands.

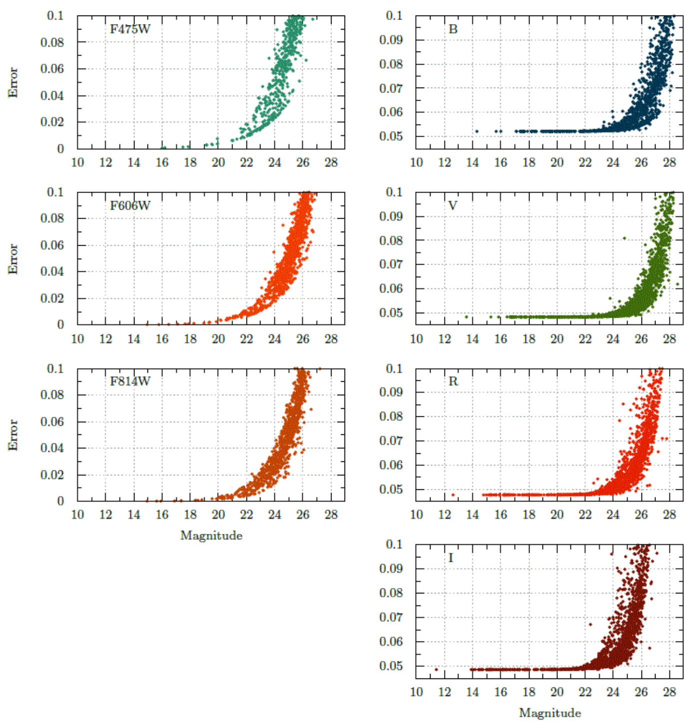


Fig1. *The magnitude-error diagram for objects extracted from GRB 021004 field. Left column graphs represent data acquired with HSC ACS camera in F475W, F606W and F814W optical bands. Right column graphs represent data of BTA BVRI bands.*

We used the Sextractor software package [16] to extract objects from the stacked BVRI image. The catalog of galaxies, extracted from this field of size 4'x4' includes 935 objects with the signal-to-noise ratio larger than 3. The following limiting magnitudes were achieved: 26.9 (B), 27.2 (V), 26.0 (Rc) and 25.5(I). We also made sure our results are consisted with HST ACS data (see Figure 1).

4. Photometric redshifts of GRB021004 field galaxies

The so-called photometric redshifts estimated from multicolor photometry turn out to be quite acceptable. The accuracy of these redshifts estimates is about 10%, which is high enough for statistical studies of the properties of distant objects. The main idea of the photometric redshift estimation is very simple: an objects multicolor photometry may be considered as a low-resolution spectrum that is used to estimate redshift [17] (see Figure 2). In practice, we estimated the photometric redshifts for the extended objects of our sample using the Hyperz software package [18]. The input data for Hyperz were: the apparent magnitudes of the objects in four bands, the internal extinction law (we used the law by Calzetti et al. [19] for starburst galaxies, which is most commonly used for studies similar to our own), the redshift range in which the solution is sought (we considered z from 0 to 4). The method is based on finding the best fit of template spectra (see Figure 3), so it is crucial to the initial model spectra. For ten of the brightest galaxies in the field we find that model spectra assigned to these galaxies are in good agreement to HST ACS data, which due to angular resolution of the images reveals the structure of these objects (see Figure 4). The field also contains four X-ray sources, for which we estimate redshift (see Figure 5). For spatial distribution of field galaxies we find a large inhomogeneity at z ~ 0.57. (see Figures 6, 7).

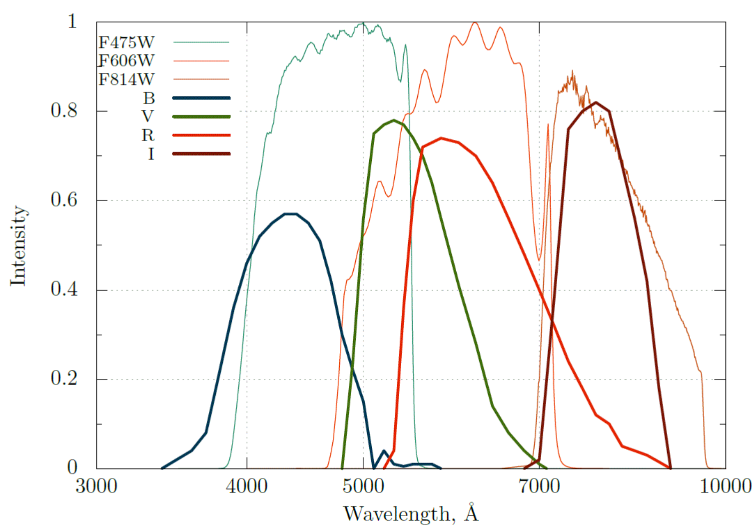


Fig2. *Filter transmission curves of HST ACS optical bands F475W, F606W. F814W and BTA BVRI optical bands.*

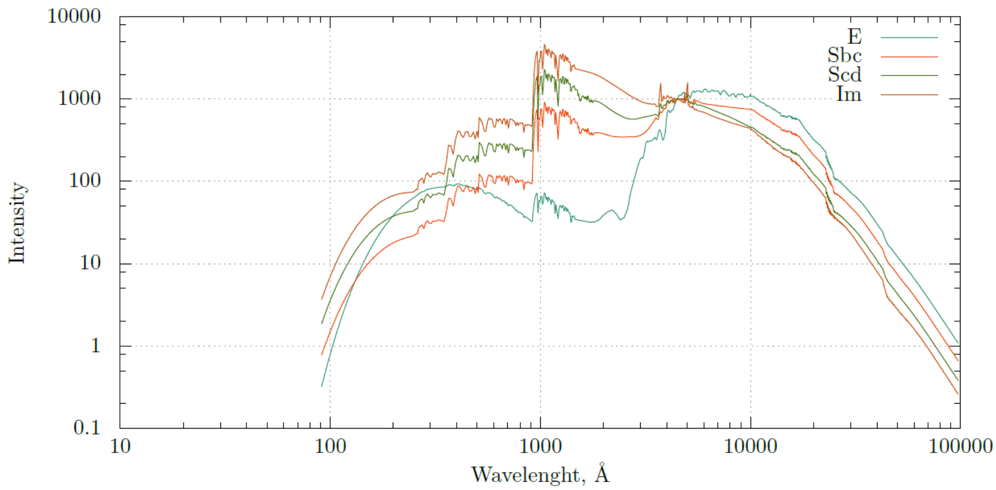
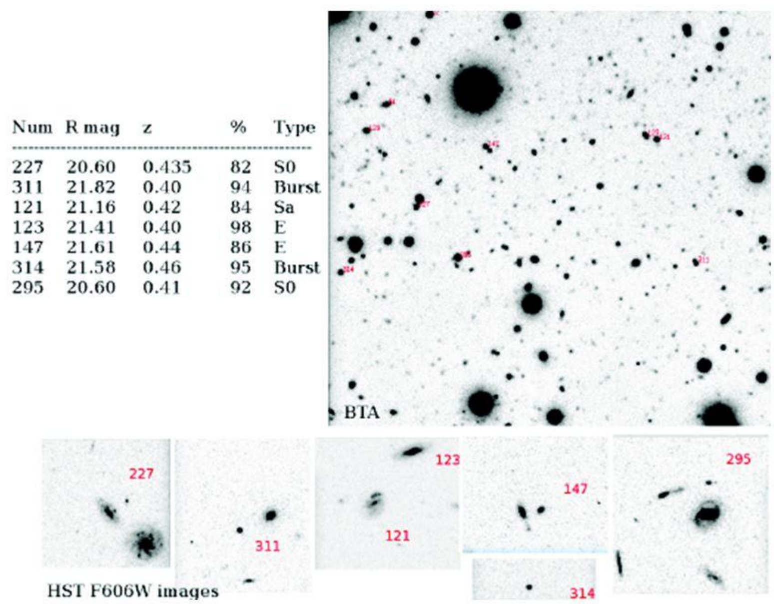


Fig3. *Template spectra of various galaxy types, used in photometric redshift calculation.*



Num	R mag	z	%	Type
227	20.60	0.435	82	S0
311	21.82	0.40	94	Burst
121	21.16	0.42	84	Sa
123	21.41	0.40	98	E
147	21.61	0.44	86	E
314	21.58	0.46	95	Burst
295	20.60	0.41	92	S0

Fig4. *Upper right image is GRB 021004 BTA field. The image is a stack of BVRI bands. Lower row of images are extracted from HST ACS F606W image.*

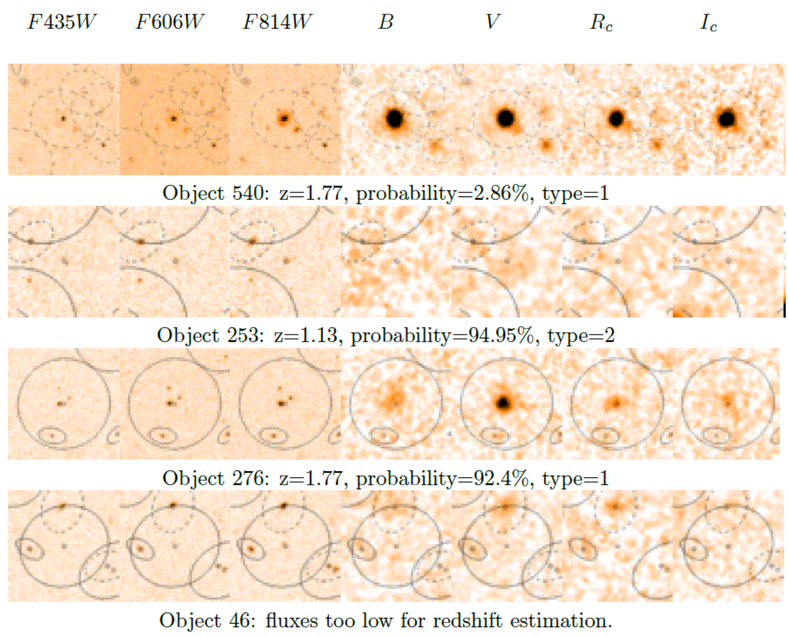


Fig5. *X-ray sources in the field of GRB021004 in HST and BTA optical bands. Object numbers are from the catalog of all extracted objects in the field.*

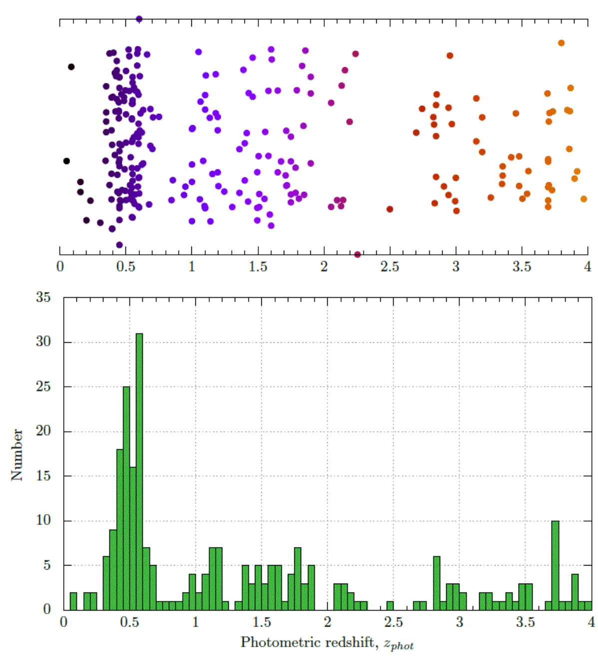


Fig6. *Spatial distribution of objects (upper) along Y axis is image coordinate, and photometric redshift distribution (lower) with a well distinguished peak at z ~ 0.57 based on BTA data.*

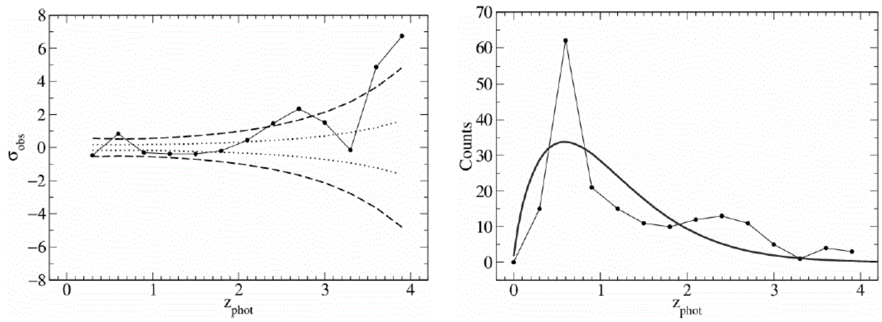


Fig7. *Deviation and Poisson noise for dz = 0.3*

The GRB 021004 afterglow spectrum has also been measured. The spectrum shows evidence of Mg II 2796/2803 redshifted at z =1.3820 and z =1.6020 (see Figure 8). Spectrum also has two features that could be identified as Mg II doublet redshifted at z= 0.57 (see Figure 9, Table 2) [12].

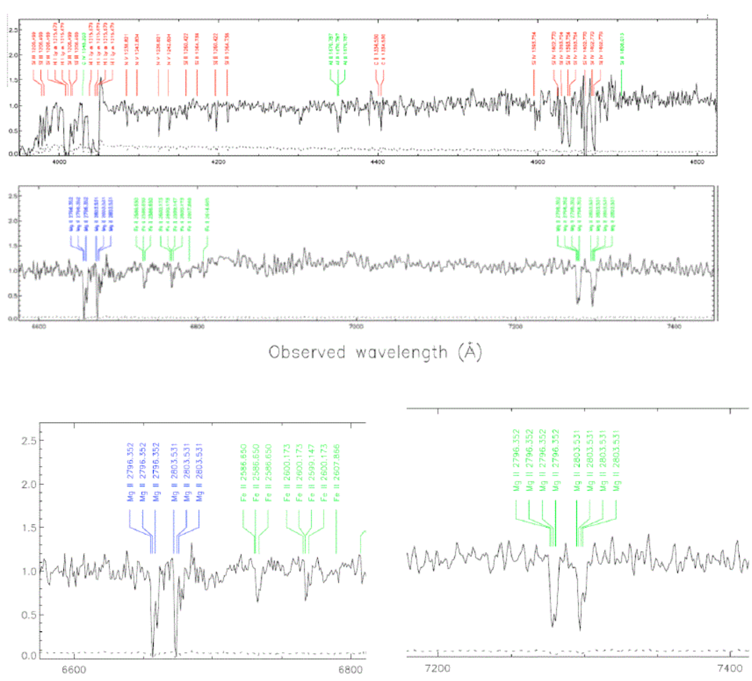


Fig8. *The selected areas of VLT/UVES spectra, obtained in REF of GRB 021004 afterglow. The lines are identified with Mg II 2796/2803. Redshifted Mg II doublet at z=1.3820 (left) and z=1.6020 (right).*

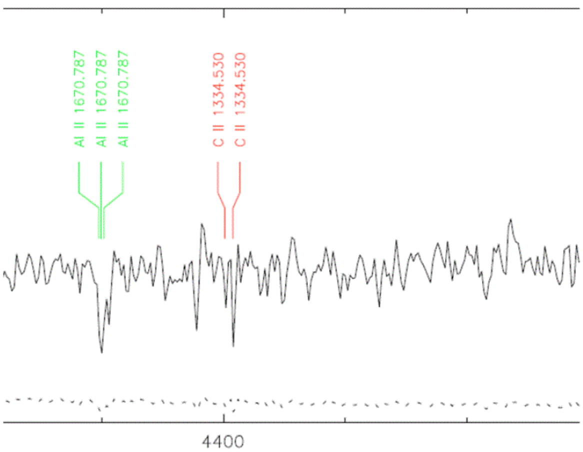


Fig9. *Features of VLT/UVES spectra identified as CII could be interpreted as Mg II doublet redshifted at z=0.57*

Table 2.

GRB	z_{GRB}	z_{abs}	W_r (λ2796) (Å)
GRB 021004	2.3295	0.5550	0.248 ± 0.025
		1.3800	1.637 ± 0.020
		1.6026	1.407 ± 0.024
GRB 050730	3.9687	1.7732	0.927 ± 0.030
		2.2531	< 0.783 (0.650)
GRB 050820A	2.6147	0.6896	0.089 ± 0.007
		0.6915	2.874 ± 0.007
		1.4288	1.323 ± 0.023
		1.6204	0.277 ± 0.024

The field of GRB 021004 has two neighboring galaxy clusters at z~0.5 at angular distances of about one degree. We examined a larger area of 3×3 degrees, which includes these two clusters, using SDSS DR12 data. SDSS survey has a limiting magnitude of about 22, and the catalog includes photometric redshift estimation as well as spectral redshifts for brighter objects. The area of 3×3 degrees is split in four regions and distribution of objects in these four regions also show peak at z~0.5 (see Fig.10). CMB Plank data for the area of 3×3 degrees shows inhomogeneities in the areas, which could witness Sunyaev-Zeldovich effect (Fig.11).

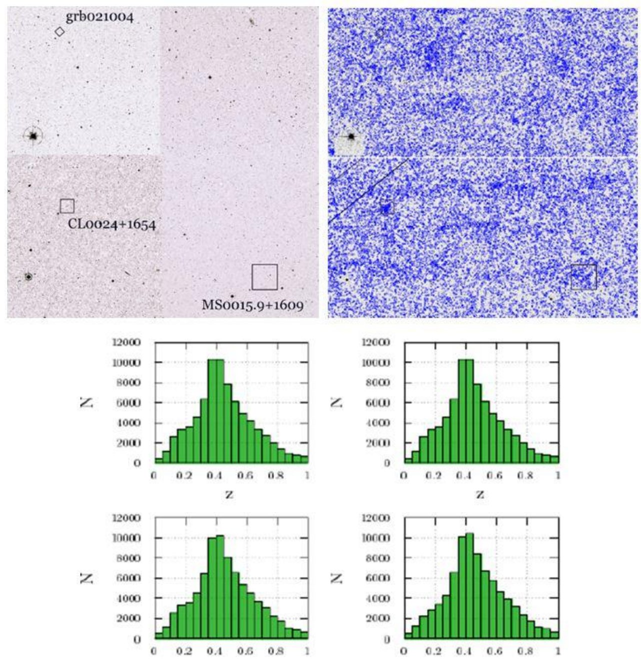


Fig10. *SDSS field of 3x3 degrees. The field containes GRB 021004 field, CL 0024+1654 galaxy cluster at z = 0.5 and MS0015.9 galaxy cluster at z=0.5 (upper left), objects in the field from SDSS DR12 survey (upper right) and distribution of objects in 3x3 field divided by four regions (bottom).*

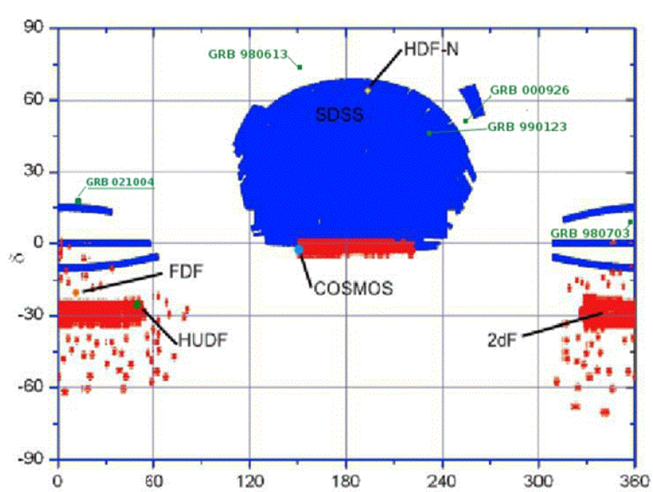


Fig11. *Sky positions of GRB 021004 field, SDSS and other surveys.*

Therefore, these signatures of BTA and HST data, absorption features in afterglow spectra of GRB021004, cosmic background radiation of Plank telescope and the investigation of BOSS survey, which is a part of SDSS could indicate a large structure of galaxies at z~0.5.

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