The field galaxies clustering in GRB lines of sight based on observations with BTA and other telescopes

Ilya V. Sokolov[1,*], Alberto J. Castro-Tirado[2], Azamat F. Valeev[3], Ilya A. Solovyev[4], Olga P. Zhelenkova[3], Oleg V. Verkhodanov[3]

[1]*Terskol Branch of Institute of Astronomy of RAS, Moscow, Russia;*

ilia.v.sokolov@gmail.com

[2]*Instituto de Astrofísica de Andalucía (IAA-CSIC), P.O. Box 03004, E-18080 Granada, Spain*

[3]*Special Astrophysical Observatory of RAS, Nizhnij Arkhyz, Russia*

[4]*Saint-Petersburg State University, SaintPetersburg, Russia*

Abstract The characteristic signs of the clustering of field galaxies were detected in the direction to gamma-ray bursts (GRBs). All accessible signs of such clustering in the lines of sight and near the location of GRB021004 were tested. The data from observations with BTA/SCORPIO, HST/ACS, VLT/UVES and from the cluster catalog SDSS-III were used. The works on photometric redshifts were reviewed.

Keywords: Gamma-Ray Bursts, Clusters, BTA Observations

1. Introduction

GRBs with large redshift *z* are good cosmological probes. They reveal clusters of galaxies on the line of sight both spectroscopically and photometrically. In this connection, mention should be made here of the article “GRBs as an instrument for testing cosmological models” by Shirokov S. I., Raikov A. A., Baryshev Yu. V., Sokolov V. V., and Vlasyuk V. V. in these Proceedings. In fact, this is also the case in a recent article [1] (see Figures 1, 2 and others there). Below, in the subsequent sections of our paper, we have reviewed also other works on the same topic, emphasizing the relevance of research in this direction.

As a concrete example, we also use here our research on the GRB 021004 field, which we began immediately after the discovery of this burst [2] (see also references there) because in interpreting the results of our observations of this GRB field we used the (new then) photometric redshifts method [3] (see also Ilya V. Sokolov’s diploma on the same topic). Here we will specifically mention the application of the same method to similar problems in the study of the distribution of galaxies in the direction of distant cosmological objects.

The study using the photometric redshifts method of clusters of galaxies is also discussed in [5]. Here, the authors present the Massive and Distant Clusters of WISE Survey (MaDCoWS), a search for galaxy clusters at $0.7 < z < 1.5$ based upon data from the Wide-field Infrared Survey Explorer (WISE) mission. A total of 1723 of the detections from the WISE – Pan-STARRS sample have also been observed with the Spitzer Space Telescope, providing photometric redshifts and richnesses, and an additional 64 detections within the WISE – SuperCOSMOS region also have photometric redshifts and richnesses. Spectroscopic redshifts for 38 MaDCoWS clusters with IRAC photometry demonstrate that the photometric redshifts have an uncertainty of $\sigma z/(1+z)$~0.036. A comparison of photometric and spectral z is shown in Figs.13 and 14 of [5].

Thus, in article [5], the possibility of detecting transitions to homogeneity using photometric redshift catalogs was studied. The method is based on measuring the fractality of the projected galaxy distribution, using angular distances, and relies only on observable quantities. It thus provides a way to test the Cosmological Principle in a model-independent unbiased way. The method was tested on different synthetic inhomogeneous catalogs, and shown that it is capable of discriminating some *fractal models* with relatively large fractal dimensions, in spite of the loss of information due to the radial projection. Also studied the influence of the redshift bin width, photometric redshift errors, bias, non-linear clustering, and surveyed area, on the angular homogeneity index in the ΛCDM cosmology. The level to which an upcoming galaxy survey will be able to constrain the transition to homogeneity will depend mainly on the total surveyed area and the compactness of the surveyed region. In particular, a Dark Energy Survey [5] – like survey should be able to easily discriminate certain fractal models with fractal dimensions.

This method will have relevant applications for upcoming large photometric redshift surveys, such as Dark Energy Survey or the Large Synoptic Survey Telescope (LSST). The same photo-z method is used in [6]. So, the photo-z method is a standard approach for estimating the redshifts of galaxies when only photometric information is available. In Figure 3 of paper [6] a representative test set performance is shown as a scatter plot and marginal distributions of 192000 spectroscopic vs. photometric redshifts. So, the photometrically derived *z* is also used in recent works [6, 7], where galaxy clusters on *z* ~ 1 are investigated.

2. Observational cosmology and GRBs afterglow monitoring using the photo-z method

The characteristic signs of the clustering of field galaxies were detected in the direction to GRB 021004. The results are set out in the series of articles [3] and [2, 8]. It is about the study of BTA, Hubble, Spitzer GRB 021004 deep field and on the clustering of galaxies around the GRB sight-line and on the excess density of field galaxies near z ~ 0.56 around the GRB 021004 position. All accessible signs of such clustering in the line of sights and near the location of the GRB were tested. The data from observations with BTA/SCORPIO, HST/ACS, VLT/UVES and from the cluster catalog SDSS-III were used.

We test for reliability any signatures of field galaxies clustering in the GRB 021004 line of sight:

The first signature is the GRB 021004 field photometric redshifts distribution based on the BTA observations with a peak near z ~ 0.56 estimated from multicolor photometry in the GRB direction.

The second signature is the Mg II 2796/2803Å absorption doublet at z ≈ 0.56 in the VLT/UVES spectra obtained for the GRB 021004 afterglow.

The third signature is the galaxy clustering in a larger (~ 3×3 degrees) area around GRB 021004 with an effective peak near z ~ 0.56 for both the spectral and photometric redshift distributions obtained from the Baryon Oscillation Spectroscopic Survey (BOSS), which is a part of the Sloan Digital Sky Survey III (SDSS-III).

And a possibility of an inhomogeneity (related with the galaxy clustering) near the

GRB 021004 direction can be also confirmed by an inhomogeneity in cosmic microwave background related with the Sunyaev-Zeldovich effect. From catalogs data the size of the whole inhomogeneity in distribution of the galaxy cluster with the peak near z ≈ 0.56 was also estimated as ~6-8 degrees.

In connection with our research, we would like to emphasize here the main observational features of GRBs noted in the literature after 1998.

So, the general characteristics of GRBs are as follows:

- Classification of the events by duration: ~ 0.2s (25%), ~ 30s (75%).
- Short and very intensive events in the high energy range.
- Counterparts of all bursts can be observed in all ranges of electromagnetic radiation (X, UV, opt, IR, radio)

Cosmological origin. After 1998, GRBs are distant and very distant (with measured *z*~10) extragalactic sources related with relativistic collapse of massive stars cores… (Though before 1998 it was supposed that GRBs are the explosions on the surface of neutron stars in the Galaxy.)

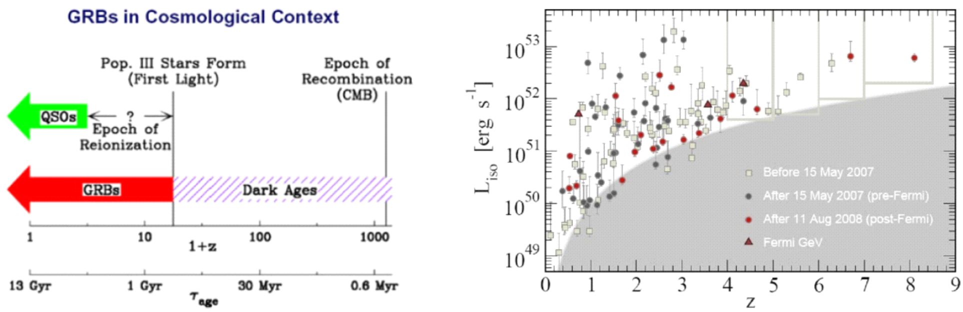

Fig1. *Left: GRBs in cosmological context. Right: from [9] — The Liso luminosity-redshift distribution of 119 Swift GRBs. Squares represent 63 GRBs used in [11], with 56 found subsequently: before (grey circles) and after (red circles) the start of Fermi. Three Fermi-LAT GeV bursts (triangles) are shown (but not used in our analysis; see also [1] and references therein).*

It is assumed that uniformity of the Universe on cosmological scales is the *fundamental* assumption of the standard cosmology that should be fulfilled even for such distant sources as GRBs. Now it is the most distant objects with measured redshifts z </~ 10 [1], [10].

In 1997-2002, there were studies [2] of GRB fields centered on the host galaxies of GRB 970508, GRB 971214, GRB 980613, GRB 980703, GRB 990123, GRB 991208, GRB 000926, GRB 021004 + investigation of surroundings of radio-source RC J0311+0507 of sizes ~ 4′×4′ (see Table 1 in [2]). The observations were carried out on the 6-m Special Astrophysical Observatory telescope using the BTA/SCORPIO instrument, and these data where supplemented with data obtained with other instruments. SDSS survey was also used. SDSS survey has a limiting magnitude of about 22, and the catalog includes photometric red-shift estimations as well as spectral red-shifts for brighter objects.

So, one of the goals of this work is to point out what can be obtained with 6-m telescope (and others) in these challenging and actual tasks, supplementing these studies with other instruments' data. And the main thing for us here is the clustering of field galaxies near GRB lines of sight.

3. The study of irregularities in the spatial distribution of distant galaxies by the method of photometric redshifts in the direction of GRBs

The GRB 021004 field: *The first signature* of the field galaxies clustering is the distribution of *photometric* redshifts in the BTA GRB 021004 field (of size of ~ 4′×4′) with a peak near z ~ 0.56, determined from the *multi-band BVRI photometry* of the field galaxies the direction of this GRB 021004 + HST/ACS data.

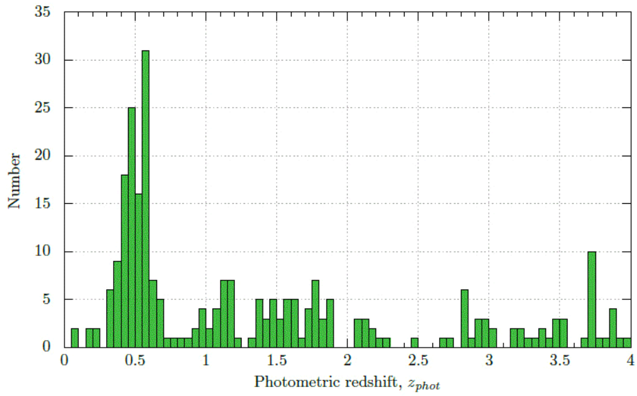

Fig2. *The photometric redshift distribution for 246 objects with the peak at z ≈ 0.56 based on BTA BV RI data [2, 9].*

The method of the photometry of GRB 021004 field is described in detail in our papers [2, 9]. We used the GRB021004 field, which was obtained as a part of GRB afterglow observations program on BTA (see Table 1 in [2, 9]). This field has exposure times of about one hour in each of the BVRI optical bands. The catalog of galaxies, extracted from this field of size 4'x4' includes 935 objects with the signal-to-noise ratio > 3. The following limiting magnitudes: 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 and data acquired with HST ACS camera in F475W (24.5), F606W (26.5) and F814W (25.5) bands. So, the photometric redshifts of GRB021004 field galaxies was estimated from the multicolor photometry and the accuracy of these redshifts 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 as follows: an objects' multicolor photometry may be considered as a low-resolution spectrum that is used to estimate redshift [2], [12]. In practice, we estimated the photometric redshifts for the extended objects of our sample using the Hyperz software package [13]. 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. [14] 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 filter transmission curves of HST ACS optical bands F475W, F606W. F814W and BTA BVRI optical bands were used**.**

So, the method is based on finding the best fit of template spectra (see in [2]), it is crucial to the initial model spectra. For ten of the brightest galaxies in the GRB 021004 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 [2]. The field also contains four X-ray sources, for which we estimate redshift. For spatial distribution of field galaxies we find a large inhomogeneity at z ~ 0.57. (see Figure 2). We emphasize here again that the template spectra of various galaxy types were used in this photometric redshift calculation.

Table1. *Redshifts for objects in the GRB21004 field.* $\mathbf{r_{SDSS}}$ *is the r-filter stellar magnitudes from the SDSS catalog,* $\mathbf{R_{BTA}}$ *is the R-filter stellar magnitude from BTA observations,* $\mathbf{z_{SDSS}}$ *is the photometric redshift from the SDSS catalog,* $\mathbf{z_{SpSDSS}}$ *is the spectroscopic redshift from the SDSS catalog,* $\mathbf{z_{BTA}}$ *is the photometric redshift obtained from BTA observations.* $\mathbf{z_{Err}}$ *is the SDSS redshift error,* ***Prob*** *is the BTA redshift probability,* ***Type*** *is the spectrum type,* ***M*** *is the absolute stellar magnitude.*

N	r_{SDSS}	R_{BTA}	z_{SDSS}	z_{SpSDSS}	z_{BTA}	$zErr$	Prob	Type	M
1	21.25	21.61	0.384	0.342	0.435	0.051	82.150	E	-19.350
2	23.46	22.34	–	0.622	0.995	–	47.310	Burst	-21.800
4	22.18	22.16	0.425	0.332	0.420	0.116	79.220	E	-18.480
5	20.87	20.60	0.398	0.581	0.410	0.099	92.530	S0	-20.010
6	21.84	21.81	0.538	0.517	0.650	0.049	2.210	Burst	-20.460
7	20.99	20.64	0.407	0.441	0.390	0.050	71.600	S0	-19.970
8	20.68	20.66	0.251	0.176	0.200	0.132	97.980	Sa	-18.270
9	20.61	20.42	0.358	0.275	0.305	0.087	98.160	Burst	-19.380
10	21.64	21.77	–	0.633	3.140	–	96.550	E	-24.130
11	21.30	21.20	0.601	0.508	0.445	0.066	97.750	E	-19.720
12	21.25	21.30	0.421	0.312	1.635	0.125	23.630	Burst	-24.360
13	21.47	22.35	0.153	0.347	0.440	0.074	73.120	Sa	-18.640
14	21.56	21.63	0.483	0.444	0.115	0.091	98.950	Burst	-15.450
15	21.38	20.78	0.755	0.631	0.525	0.066	73.850	E	-20.930
16	20.00	19.99	0.310	0.564	0.290	0.063	99.420	Burst	-19.850
17	21.97	21.76	0.497	0.530	0.465	0.078	87.750	Burst	-19.300
18	20.78	20.82	0.459	0.603	0.405	0.058	50.330	E	-19.750
20	21.76	22.34	0.371	0.328	0.455	0.045	80.380	S0	-18.630
21	21.31	21.42	0.747	0.603	1.130	0.042	0.000	Burst	-22.720
22	21.38	21.41	0.609	0.675	0.405	0.088	98.440	E	-19.240
23	21.89	21.51	0.502	0.146	0.420	0.123	84.200	Sa	-19.170
24	20.91	21.05	0.388	0.420	0.440	0.049	49.290	E	-19.910
25	21.96	22.10	0.413	0.512	0.355	0.061	72.790	Burst	-17.930
26	21.27	20.98	0.474	0.543	0.660	0.097	99.000	Burst	-21.280
27	21.25	21.81	0.436	0.515	0.400	0.063	93.860	Burst	-18.920
28	22.05	21.20	–	0.670	0.695	–	96.540	Burst	-21.580
29	25.30	24.53	0.664	0.790	0.480	0.151	42.830	E	-16.790
35	20.69	20.61	0.440	0.281	0.255	0.120	98.630	E	-18.730
41	20.64	20.54	0.403	0.581	0.395	0.070	77.230	E	-20.110
42	20.95	21.02	0.503	0.537	0.350	0.097	95.490	S0	-19.300
43	19.06	19.01	0.301	0.325	0.260	0.028	90.410	Sa	-20.440
44	20.50	20.42	0.413	0.171	0.255	0.148	92.470	E	-18.760
50	21.62	21.68	0.407	0.436	0.340	0.097	86.800	E	-18.690
51	21.85	21.83	0.673	0.827	0.650	0.093	28.910	Burst	-20.550
52	22.10	21.80	0.120	0.023	1.605	0.089	0.020	Burst	-24.200
55	21.34	22.10	–	0.178	0.440	–	76.270	Sa	-18.890
58	21.99	21.56	0.534	0.685	0.450	0.055	95.600	Burst	-19.360
59	21.89	21.65	0.467	0.513	0.550	0.034	37.430	Burst	-20.050
61	22.67	22.61	0.594	0.723	0.715	0.093	90.770	Burst	-20.000
62	22.29	22.01	0.521	0.567	1.770	0.038	2.850	Burst	-23.450
70	20.41	20.44	0.319	0.335	0.150	0.095	85.840	Burst	-17.770
82	21.03	21.54	0.373	0.288	2.650	0.184	99.990	Burst	-23.410
83	21.69	22.05	0.099	0.090	0.095	0.062	97.530	Burst	-15.530
93	21.71	22.16	0.525	0.479	0.340	0.087	86.130	E	-18.210
94	22.05	21.83	0.465	0.413	0.345	0.082	95.950	S0	-18.520
99	22.62	22.04	–	0.323	0.200	–	99.980	S0	-16.710

Paper [14] on the VLT/UVES of GRB 021004 afterglow spectra shows three parts of the UVES spectrum of GRB 021004 afterglow with the doublet Mg II 2796/2803. So, here we have **The second signature** – the absorption doublet Mg II 2796/2803Å at the redshift $z \approx 0.56$ detected in the same VLT/UVES spectrum of the GRB 021004 afterglow of this GRB, i.e. on the line of sight of the GRB. Totally the following was detected there:

Mg II doublet at z= 2.3295 [GRB],

Mg II doublet at z= 1.6020,

Mg II doublet at z= 0.570 (identified also in SAO).

And here (on BTA) we have also the same doublet (with the same spacing between components) is outlined, but at z = 0.570.

Analogous cases were observed by other authors and for other GRBs. For example, see [15] on the clustering of galaxies around GRB sight-lines. In Introduction of their paper it is said that:

- There is evidence of an overdensity of strong intervening MgII absorption line systems distributed along the lines of sight towards GRB afterglows relative to quasar sight-lines. If this excess is real, one should also expect an overdensity of field galaxies around GRB sight-lines, as strong MgII tends to trace these sources.
- And in spectra by A. J. Castro-Tirado et al. [14] for GRB 021004 afterglow such MgII absorption line systems are as many as 3.

Considering the redshift ranges $0.37 < z < 2.27$ of the SDSS survey, an excess of strong intervening MgII systems was found along the 10 GRB lines of sight observed by VLT-UVES of a factor of ~ 2 compared to QSO lines of sight [16].

But we see ourselves the 3-d system with $z \approx 0.57$ in our BTA GRB 021004 afterglow spectra, though this MgII absorption at z=0.5550 (near Al II 1670 at z=1.6026) was first identified.

See also the above-mentioned study of GRB 021004 optical afterglow with the 8.2m VLT (UVES & ISAAC) between 10 and 14 hours after the onset of the event [14].

The paper also analyzed the distribution of matter around the progenitor star of GRB 021004 as well as the properties of its host galaxy with high-resolution echelle as well as near-infrared spectroscopy. Observations were taken by the 8.2m Very Large Telescope with the Ultraviolet and Visual Echelle spectrograph (UVES) and the Infrared Spectrometer And Array Camera (ISAAC) between 10 and 14 hours after the onset of the event.

And, at last, the ***third signature***, related to this already well-studied field around GRB 021004: on the clustering of galaxies in a larger area (>/~ 3×3 sq. degrees) around GRB 021004 with the effective peak near $z \sim 0.56$, detected from distributions of spectral and ***photometric redshifts*** from the Baryon Oscillation Spectroscopic Survey (BOSS), which is a part of the Sloan Digital Sky Survey III (SDSS-III).

Distributions over photometric redshifts in the fields of ~6-8 degrees near $z \approx 0.56$ were also studied by data from 6 catalogs (see Figure 3):

1) redMaPPer DR8 cluster catalog [17] (Rykoff et al., AJ 785, 104, 2014),

2) Group catalogues of the local universe [18] **(**Saulder et al., A&A 596, A14, 2016),

3) Newly rich galaxy clusters identified in SDSS-DR12 [19] **(**Wen et al., AJ 807, 178, 2015),

4) Northern Optical Cluster Survey [20] **(**Gal et al., AJ 137, 2981, 2009),

5) Richness of galaxy clusters [21] **(** Oguri, MNRAS 444, 147, 2014),

6) Flux- and volume-limited groups for SDSS galaxies [22] **(**Tempel et al., A&A 566, A1, 2014).

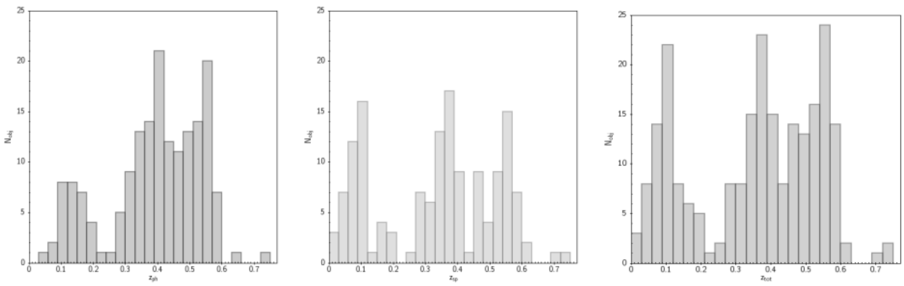

Fig3. *The data from of 6 catalogs: the size of the whole irregularity is ~ 6–8 degrees in the distribution of galaxy clusters with the peak near z ≈ 0.56 was also estimated.*

So, the presence of a cluster near z ≈ 0.56 does not contradict the spectroscopy of the GRB021004 afterglow and one galaxy of this cluster turned out to be at the GRB line of sight at least… This could be determined if the spectroscopy with БТА & HST or narrow-band observations of the area of the host galaxy were carried out. Most probably, the irregularity with z ~ 0.57 in the direction to GRB021004 is a part of a huge supercluster and the study of the GRB 021004 area confirms the presence of an irregularity at z=0.57.

Then the origin of other systems of absorption lines (z*abs*) in spectra of this and other afterglows becomes understandable: for more distant clusters it is not a single galaxy, but the whole cluster that gets to the spectrograph slit. That is why the lines of this doublet are stronger at high z.

A possibility of inhomogeneity (a galaxy clustering) near the GRB 021004 direction can be also confirmed by an *inhomogeneity* in cosmic microwave background (CMB) related with the Sunyaev-Zeldovich effect. From CMB catalogs data *the size* of the whole inhomogeneity in distribution of the galaxy cluster with the peak near z ≈ 0.56 was also estimated as ~6-8 degrees [23]. Thus, the distribution of GRBs from catalogs of the BATSE and BeppoSAX space observatories relative to the cosmic microwave background (CMB) data by Planck space mission is studied. Three methods were applied for the data analysis:

1) a histogram of CMB signal values in GRB directions,

2) mosaic correlation maps calculated for GRB locations and CMB distribution,

3) calculation of an average response in the area of “an average population GRB” on the CMB map.

A correlation between GRB locations and CMB fluctuations was detected which can be interpreted as systematic effects in the process of observations. Besides, in averaged areas of CMB maps, *a difference between distributions of average fluctuations for short and long GRBs was detected*, which can be caused by different natures of these events.

The CMB fluctuations in direction of GRBs were also studied in the paper [23] on statistics of the Planck CMB signal in direction of gamma-ray bursts from the BATSE and BeppoSAX catalogs. See also [24] on the optical identifications of high-redshift galaxy clusters from Planck Sunyaev-Zeldovich survey, which presents the results of optical identifications and spectroscopic redshifts measurements for galaxy clusters from 2-nd Planck catalogue of Sunyaev-Zeldovich sources (PSZ2), located at high redshifts, z ~ 0.7–0.9. The paper used the data of optical observations obtained with the Russian-Turkish 1.5-m telescope (RTT150), the Sayan observatory 1.6-m telescope, the Calar Alto 3.5-m telescope and the 6-m SAO RAS telescope. Spectroscopic redshift measurements were obtained for seven galaxy clusters, including one cluster, PSZ2 G126:57+51:61, from the cosmological sample of PSZ2 catalogue.

In central regions of two clusters, PSZ2 G069:39+68:05 and PSZ2 G087:39-34:58, the strong gravitationally lensed background galaxies are found, one of them at the redshift z ~ 4.262. The data presented below roughly double the number of known galaxy clusters in the second Planck catalogue of Sunyaev-Zeldovich sources at high redshifts, z ~ 0.8.

The giant ring-like structures at 0.78 < z < 0.86, formed by GRBs was also mentioned in [25], where a giant ring-like structure at 0.78<z<0.86 displayed by GRBs was detected.

So, the clustering of galaxies (and around GRB sight-lines) are discovered and investigated in detail in very many papers already – see, e.g., in [26]. Following the detection of GRB 161017A by Swift (Troja et al. GCNC 20064), *Fermi* (Hui and Meegan, GCNC 20068) and *Lomonosov* (Sadovnichy et al. GCNC 20075), we observed the optical afterglow (Yurkov et al. GCNC 20063; Breeveld and Troja, GCNC 20074) with the 10.4m Gran Telescopio Canarias (GTC) at the Spanish island of La Palma, starting at 05:59 UT on Oct 18 (i.e. 12.1 hr post-burst), covering a combined range of 3800-10000 A. The reddest spectrum (convering the range between 7350 and 10000 A at a resolution of 2500) shows the strong Mg II doublet at a redshift z = 2.0127, consistent with the value reported by de Ugarte Postigo et al. (GCNC 20069). We also identify, in the bluest spectrum, other absorption lines (eg. SiII, FeII) and the two intervening systems reported on their GTC (+OSIRIS) R1000B spectrum taken 1.3 hr earlier than us.

Mg II doublet at z= 0.916
Mg II doublet at z= 1.370
Mg II doublet at z= 2.0127 [GRB]

4. Conclusions

Thus, the study of the GRB 021004 field confirms the presence of a cluster at z=0.57 also.

Then the origin of other absorption line systems (zabs) in spectra of this and other afterglows becomes clear [27]. And for more distant galaxies it is not a single galaxy, but the whole cluster gets to the spectrograph slit. That is why the lines of this doublet (and other lines also) are stronger at higher z. All these systems can be related to analogous clusters at *large z*, as is observed for a long time in direction to QSOs. See also [28], [29] where the galaxy clusters in the range $0.2 \lesssim z \lesssim 0.9$ were found and quantifying the suppression of the (un)-obscured star formation in galaxy cluster cores at $0.2 \lesssim z \lesssim 0.9$ studied.

We note here also that only direct optical identification of neutrino and gravitational events can confirm or disprove a particular model of their source, as was in the case with identification, and subsequent choice of a theoretical model for GRB sources. Until 1998, it was believed that these are explosions in the Galaxy on the surface of neutron stars. After 1998, it turned out that these are still extragalactic sources ($z \leq 10$) associated with supernova explosions and the relativistic collapse of the nuclei of massive stars...

See also the report by Alberto J. Castro-Tirado, Vladimir V. Sokolov and Sergey S. Guziy “Gamma-ray bursts: Historical afterglows and early-time observations” in Proceedings of the International Conference [30], which discusses the GRB afterglows (GRB 920723 and 920925C) prior to the Afterglow Era that started in 1997. There it is shown how we used observations obtained with the 6-meter BTA in Zelenchuk (Russia) and the 10.4-m GTC in La Palma (Spain) for the study of GRB afterglows and their host galaxies. Moreover, when completed with our BOOTES Global Network of 0.6-meter robotic telescopes, this result had completed studying the early phases starting seconds after the trigger. Since the discovery of the afterglows to GRBs in 1997, much has been advanced in the field, with several hundreds of counterparts in the last 20 yr in all the electromagnetic range from radio to gamma-rays, ending up with the detection of gravitational waves associated to a short-duration GRB in 2017 (GRB 170817/GW 170817).

The new Era of Gravitational Wave Astronomy was discussed at the previous (third) conference "The multi-messenger astronomy: gamma-ray bursts, search for electromagnetic counterparts to neutrino events and gravitational waves" (7-14 October 2018). See the talk by A.J.Castro-Tirado [31] on "The monitoring of gamma-ray burst afterglows and search for optical counterparts to neutrino events and gravitational wave signals".

This talk emphasized that "the new Era of Gravitational Wave Astronomy has just been opened thanks to the detection of the first electromagnetic counterpart to GW 170817 and will discuss the implications of the short-duration GRB associated to it, just before the opening of the forthcoming O3 LIGO-Virgo run in 2019."

References

[1] Tomoya Kinugawa, Yuichi Harikane, Katsuaki Asano, "Long gamma-ray burst rate at very high redshift", arXiv:1901.03516 and all references therein.

[2] Sokolov Ilya V., Castro-Tirado A.J., Verkhodanov O.V., Zhelenkova O.P., Baryshev Yu.V. "Clustering of galaxies around the GRB 021004 sight-line at z ~ 0.5", in "Proceedings of the International Workshop on Quark Phase Transition in Compact Objects and Multimessenger Astronomy: Neutrino Signals, Supernovae and Gamma-Ray Bursts", Russia, Nizhnij Arkhyz (SAO RAS), Terskol (BNO INR RAS), October, 7 - 14, 2015, Publishing house "Sneg", Pyatigorsk, 2016, pp. 111-120

[3] Yu. V. Baryshev, Ilya V. Sokolov, Alex S. Moskvitin et al., "Study of Faint Galaxies in the Field of GRB 021004", Astrophysical Bulletin, 65, 311 (2010)

[4] D. Alonso et al., "Measuring the transition to homogeneity with photometric redshift surveys" , arXiv:1312.0861

[5] Anthony H. Gonzalez, Daniel P. Gettings, Mark Brodwin, et al., "Galaxy Clusters at z~1 The Massive and Distant Clusters of WISE Survey. I: Survey Overview and a Catalog of >2000 Galaxy Clusters at z~1", arXiv:1809.06820

[6] Kristen Menou, "Morpho-Photometric Redshifts", arXiv:1811.06374, submitted in MNRAS.

[7] Jasleen Matharu, Adam Muzzin, Gabriel B. Brammer, et al., "HST/WFC3 grism observations of z ~ 1 clusters: The cluster vs. field stellar mass-size relation and evidence for size growth of quiescent galaxies from minor mergers", arXiv:1811.06548

[8] Ilya V. Sokolov, Oskar J.A. Bravo Calle, and Yu.V. Baryshev , "Study of BTA, Hubble, and Spitzer GRB 021004 deep field", in "Gamma–ray Bursts: 15 Years of GRB Afterglows – Progenitors, Environments and Host Galaxies from the Nearby to the Early Universe" (A.J. Castro-Tirado, J.Gorosabel and I.H. Park (eds)), EAS Publications Series, 61 (2013) 435-437 (2013).

[9] I. V. Sokolov, A. J. Castro-Tirado, O. P. Zhelenkova, I. A. Solovyev, O. V. Verkhodanov, and V. V. Sokolov. "The Excess Density of Field Galaxies near z ~ 0.56 around the Gamma-Ray Burst GRB021004 Position", (Astrophysical Bulletin, Vol. 73, No. 2, 2018 p.111 and see in arXiv:1805.07082).

[10] Matthew D. Kistler, Hasan Yuksel, John F. Beacom, Andrew M. Hopkins, J. Stuart B. Wyithe, "The Star Formation Rate in the Reionization Era as Indicated by Gamma-ray Bursts", Astrophys.J.705:L104-L108,2009, arXiv:0906.0590

[11] Matthew D. Kistler, Hasan Yuksel, John F. Beacom, Andrew M. Hopkins, J. Stuart B. Wyithe , "The Star Formation Rate in the Reionization Era as Indicated by Gamma-ray Bursts", Astrophys.J.705:L104-L108,2009, arXiv:0906.0590

[12] G. E. Prochter, J. X. Prochaska, and S. M. Burles, Astrophys. J. 639, 766 (2006).

[13] S. D. Vergani, P. Petitjean, C. Ledoux, et al., Astron. and Astrophys. 503, 771 (2009).

[14] A. J. Castro-Tirado, P. Møller, G. Garc´ıa-Segura, et al., "GRB 021004: Tomography of a gamma-ray burst progenitor and its host galaxy", Astron. and Astrophys. 517, A61 (2010), arXiv1004.1131

[15] Vladimir Sudilovsky, Jochen Greiner, Arne Rau, Mara Salvato, Sandra Savaglio, Susanna D. Vergani, et al., Clustering of galaxies around GRB sight-lines, arXiv:1302.6362

[16] Vergani, S. D., Petitjean, P., Ledoux, C. et al. MgII absorbers along GRB lines of sight observed with VLT-UVES, 2009, A&A, 503, 771 (arXiv:0906.3269)

[17] Rykoff et al., AJ 785, 104 (2014)

[18] Saulder et al., A&A 596, A14 (2016)

[19] Wen et al., AJ 807, 178 (2015),

[20] Gal et al., AJ 137, 2981 (2009),

[21] Oguri, MNRAS 444, 147 (2014),

[22] Tempel et al., A&A 566, A1 (2014).

[23] M.L.Khabibullina, O.V.Verkhodanov, V.V.Sokolov, Astrophysical Bulletin, 2014, No 69, Vol.4, Statistics of the Planck CMB signal in direction of gamma-ray bursts from the BATSE and BeppoSAX catalogs) arXiv:1406.6480, Astrophysical Bulletin, 2014, No 69, Vol.4

[24] R. A. Burenin, I. F. Bikmaev, I. M. Khamitov, I. A. Zaznobin, G. A. Khorunzhev, M. V. Eselevich, V. L. Afanasyev, S. N. Dodonov, J. A. Rubiño-Martín, N. Aghanim, R. A. Sunyaev arXiv:1801.04464 Optical identifications of high-redshift galaxy clusters from Planck Sunyaev-Zeldovich survey,

[25] Balazs, et al., arXiv:1507.00675, Accepted for publication in MNRAS,

[26] GCN CIRCULAR 20077, GRB 161017A: GTC additional spectroscopy and refined redshift DATE: 16/10/18 18:18:16 GMT (12.1 hr post-burst, A. J. Castro-Tirado (IAA-CSIC), A. F. Valeev, V. V. Sokolov et al.]

[27] Susanna D. Vergani et al.: MgII absorbers along GRB lines of sight observed with VLT-UVES, A&A 503, 771 (2009)

[28] Andrews et al., "Galaxy clusters in the line of sight to background quasars. III. Multi-object spectroscopy", The Astrophysical Journal, vol. 774, iss.1. arXiv:1306.6117

[29] L. Rodríguez-Muñoz, G. Rodighiero, C. Mancini, et al. "Quantifying the suppression of the (un)-obscured star formation in galaxy cluster cores at $0.2 \lesssim z \lesssim 0.9$", arXiv:1812.08804, submitted to MNRAS

[30] Alberto J. Castro-Tirado, Vladimir V. Sokolov and Sergey S. Guziy "Gamma-ray bursts: Historical afterglows and early-time observations, pp. 41-50 in Proceedings of the International Conference SN 1987A (2-8 July 2017), "Quark Phase Transition in Compact Objects and Multimessenger Astronomy", http://www.sao.ru/hq/grb/conf_2017/proceedings.html

[31] A.J.Castro-Tirado (Instituto de Astrofisica de Andalucia IAA-CSIC, Granada, Spain). “The monitoring of gamma-ray burst afterglows and search for optical counterparts to neutrino events and gravitational wave signals”. (see the site https://www.sao.ru/hq/grb/conf_2018/program.html