Gamma Ray Bursts and their relationship to the interstellar matter NN-111016

Final report

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1 Analysis of the Swift satellite data

1.1 Survival analysis

Using the survival analysis We studied the unbiased luminosity distribution of the host galaxies of GRBs. We found a relationship between the Swift GRB data and the host galaxies' data, observed by the Keck telescope. We obtained the studied sample by merging the Swift GRB Table and the Keck optical data. Based on the DEEP2 catalogue of galaxies we compared the brightness distribution of the host galaxies with that of the those in the field. We found that the host galaxies of GRBs are systematically fainter and bluer then those in the field, showing that the bursts are more frequent in the galaxies of higher SFR and lower mass.

1.2 X-ray spectra and the N(H) neutral Hydrogen column density

Two types of emission can be observed from gamma-ray bursts (GRBs): the prompt emission from the central engine which can be observed in gamma or X-ray and the afterglow originated in the environment in X-ray and at lower frequencies. The correct estimation of the galactic interstellar medium is very important because we observe the host emission together with the galactic hydrogen absorption. We found that the estimated intrinsic hydrogen column density and the X-ray flux strongly depend on the redshift and the galactic foreground hydrogen.

The Swift satellite has observed more than a thousand GRBs with X-ray data. Almost a third of them have redshift measurement, too. We analyzed the X-ray spectral fitting of the data of detected N(H) absorption. We studied the change of the intrinsic hydrogen column density during the outburst in a few cases. No significant variability of N(H) column density was identified.

1.3 Detailed study of GRB141121A – ULGRB

We performed an extensive observational campaign on the Swift-discovered GRB 141121A. Our observations covered radio through X-rays and extended for more than 30 days after discovering the burst. The prompt phase of GRB 141121A lasted 1410 s and, at the derived redshift of $\mathrm{z} = 1.469$, the isotropic energy is $\mathrm{E}_{\gamma,\mathrm{iso}} = 8.0 \times 10\mathrm{e}52$ erg. Due to the long prompt duration, GRB 141121A falls into the recently discovered class of ultra-long GRBs (UL-GRBs). Peculiar features of this burst are (1) a flat early-time optical light curve and (2) a radio-to-X-ray rebrightening around three days after the burst. The latter is followed by a steep optical-to-X-ray decay and a much shallower radio fading.

We analyzed GRB141121A in the context of the standard forward-reverse shock (FS, RS) scenario and we disentangle the FS and RS contributions. Finally, we comment on the puzzling early-time ($\mathrm{t} \leq 3$

days) behavior of GRB 141121A, and suggest that its interpretation may require a twocomponent jet model. Overall, our analysis confirms that the class of UL-GRBs represents our best opportunity to firmly establish the prominent emission mechanisms in action during powerful gamma-ray burst explosions, and future missions (like SVOM, XTiDE, or ISSLobster) will provide many more of such objects.

1.4 Statistical classification of GRBs

Two decades ago two classes of gamma-ray bursts were identified and delineated as having durations shorter and longer than about 2 seconds. Subsequently indications also supported the existence of a third class.

Using maximum likelihood estimation we analyze the duration distribution of 888 Swift BAT bursts. Fitting three log-normal functions to the duration distribution of the bursts provides a better fit than two log-normal distributions, with 99.9999% significance. Similarly to earlier results, we found that a fourth component is not needed. The relative frequencies of the distribution of the groups are 8% for short, 35% for intermediate and 57% for long bursts which correspond to our previous results.

We analyzed the redshift distribution for the 269 GRBs of the 888 GRBs with known redshift. We find no evidence for the previously suggested difference between the long and intermediate GRBs' redshift distribution. The observed redshift distribution of the 20 short GRBs differs with high significance from the distributions of the other groups.

2 Studies with the Fermi Gamma-ray Space Telescope

2.1 Studies with Fermi LAT data

2.1.1 Studying GRB jets

We studied a high energy model of the GRBs where a dissipative photosphere is responsible for the usual spectral peak in the MeV energy range, accompanying a thermal component. We treat the initial acceleration of the jet in a usual way, taking into account the outflow of the matter dominated by the magnetic field and barionic matter. In this model we connected the GeV energy with the observations of the GRBs detected by Fermi LAT. Based on the recently discovered relationship between the thermal and non-thermal peaks in some GRBs we concluded that the jet is dominated by the barionic matter or the Poynting flux.

The bright, short, and hard GRB090510 was detected by all instruments aboard the Fermi and Swift satellites. The multi-wavelength observations of this burst presented similar features to the Fermi-LAT-detected gamma-ray bursts. In the framework of the external shock model of early afterglow, a leptonic scenario that evolves in a homogeneous medium is proposed to revisit GRB090510 and explain the multi-wavelength light curve observations presented by this burst.

These observations are consistent with the evolution of a jet before and after the jet break. The long-lasting LAT, X-ray, and optical fluxes are explained in the synchrotron emission from the adiabatic forward shock. Synchrotron self-Compton emission from the reverse shock is consistent with the bright LAT peak provided that the progenitor environment is intertwined with strong magnetic fields. It could provide compelling evidence of magnetic field amplification in the neutron star merger.

2.1.2 Early VLA and multi-wavelength study of GRB130907A

We performed a multi-wavelength study of GRB130907A, a burst of hiper-high energy. he burst was detected by the Swift satellite and the first radio-detection was made only 4 hours after the trigger. The GRB130907A was also detected by the Fermi-LAT telescope. In course of time the hard X-ray spectrum of the burst changed significantly. The radio observation was made at the > 10 GHz frequency range. We modelled the data obtained from the broad radio frequency range. And determined the physical parameters of the fireball which resulted in the burst.

These parameters were in the typical range of such phenomena except the flux density which was higher than anticipated. This finding indicates the significance of the early radio observations of these afterglows.

2.1.3 Multi-wavelength study of GRB160625B

GRB160625B, one of the brightest bursts in recent years, was simultaneously observed by Fermi and Swift satellites, and ground-based optical telescopes in three different events separated by long periods of time. The non-thermal multi-wavelength observations of GRB160625B are described and a transition phase from wind-type-like medium to interstellar medium between the early and the late afterglow is found.

The multi-wavelength observations of the early afterglow are consistent with the afterglow evolution in a stellar wind medium whereas the observations of the late afterglow are consistent with the afterglow evolution in ISM. The wind-to-ISM transition is calculated to be at ~830 s when the jet has decelerated, at a distance of ~2.2×10^{17} cm from the progenitor. The derived values of the magnetization parameter, the slope of the fast decay of the optical flash and the inferred magnetic fields suggest that Poynting flux-dominated jet models with arbitrary magnetization could account for the spectral properties exhibited by GRB160625B.

2.1.4 Estimation of the IGMF

The magnetic field in intergalactic space gives important information about magnetogenesis in the early Universe. The properties of this field can be probed by searching for radiation of secondary e+ e- pairs created by TeV photons, that produce GeV range radiation by Compton-scattering cosmic microwave background (CMB) photons. The arrival times of the GeV "echo" photons depend strongly on the magnetic field strength and coherence length. We developed a Monte Carlo code, accurately treats pair creation, simulating the spectrum and time-dependence of the echo radiation. The extrapolation of the spectrum of powerful GRBs like GRB130427A to TeV energies is used to demonstrate how the intergalactic magnetic field (IGMF) can be constrained if it is in the $10^{-21} - 10^{-17}$ G range at 1 Mpc coherence length.

2.2 The GRB170817A/GW170817 merger event

We participated in the direct observation of GRB170817A by the Fermi GBM, associated with the LIGO-Virgo GW170817 gravitational wave source neutron star merger event. This GRB lacks the short duration and hard spectrum of a Short gamma-ray burst (GRB) expected from long-standing classification models. Correctly identifying the class to which this burst belongs requires comparison with other GRBs detected by the Fermi GBM. Classification of GRB170817A/GW170817 showed that it is most likely belongs to the Intermediate, rather than the Short GRB class. It appears that GRB classification schemes may not yet be linked to appropriate theoretical models, and that theoretical models may not yet adequately

account for known GRB class properties. We conclude that GRB170817A may not fit into a simple phenomenological classification scheme.

The first joined GRB-gravitational wave observation allows us to link the details of the central engine properties to GRB emission models. We found that photospheric models (both dissipative and non-dissipative variants) have difficulties accounting for the observations. Internal shocks give the most natural account of the observed peak energy, viewing angle and total energy. We also showed that a simple external shock model can reproduce the observed GRB pulse with parameters consistent with those derived from the afterglow modeling. We found a simple cocoon shock breakout model is in mild tension with the observed spectral evolution, however it cannot be excluded based on gamma-ray data alone. Future joint observations of brighter GRBs will pose even tighter constraints on prompt emission models.

2.3 Automatic detector weight optimalization (ADWO)

We developed the Automatized Detector Weight Optimization (ADWO) algorithm, which is an analysis tool for multi-channel multi-detector signals for looking electromagnetic transients in a given time interval. Provided that the trigger time of an astrophysical event is well known (as in the case of a gravitational wave detection), ADWO combines the data of all detectors and energy channels to provide the best signal-to-noise ratio. It is an efficient unsupervised data analysis algorithm to identify electromagnetic events in the Fermi's Gamma-ray Burst Monitor CTTE data stream, hence it can provide a strong, independent test to any electromagnetic signal accompanying future gravitational wave observations.

Using ADWO we can successfully identify any potential electromagnetic counterpart of gravitational wave events, as well as to detect previously un-triggered short-duration GRBs in the data-sets. We applied ADWO on the GRB150522B, GW150914 and LVT151012 transients and obtained the corresponding false alarm probabilities of 2.8×10^{-5}, 0.0075, and 0.037. We also applied ADWO for the GW151226 and GW170104 events, where no corresponding EM signal was detected neither by ADWO nor by other groups.

The GRB170817A/GW170817 merger event's Fermi GBM data was also analysed: here ADWO provided a strong signal at the same position where GRB170817A was observed.

The ADWO method is currently under development, we working on it to enhance and apply for for other space-borne detectors beside Fermi's GBM, e.g. for RHESSI and the Integral detectors. The physically plausible search space will also be constrained by using the information extacted from the detector response matrix (where it is obtainable) - this can provide crude directional information.

2.4 Statistical properties of Fermi GRB spectra

Studying their gamma-ray spectra may reveal some physical information on γ-ray bursts (GRBs). The Fermi satellite has observed more than 2,000 GRBs.

The Fermi Gamma Burst Monitor catalogue contains GRB parameters (peak energy, spectral indices, and intensity) estimated by fitting the gamma-ray spectral energy distribution of the total emission (fluence), and during the time of the peak flux. Using contingency tables we revealed an ordering of the spectra into a power law – Comptonized – smoothly broken power law – Band series. This result was further supported by a correspondence analysis of the peak flux and fluence spectra categorical variables.

Linear discriminant analysis (LDA) found a relationship between categorical (spectral) and model independent physical data. LDA resulted in highly significant physical differences among the spectral types. This spectral variability is confirmed by the differences in the low-energy spectral index and peak energy, between the peak flux and fluence spectra. We found that the synchrotron radiation is significant

in GBM spectra. The mean low-energy spectral index is close to the canonical value of $-2/3$ of the syncrotron radiation during the time of the peak flux. However, it is approx. -0.9 for the spectra of the fluences, obtained from the total duration of the burst. We interpreted this difference as showing that the effect of cooling is important only for the fluence spectra.

Making use LDA we found a relationship between the spectral categories and the model-independent physical data. We compared the Swift and Fermi spectral types, and found a relationship between the Fermi fluence spectra and the Swift spectra, but the result of the peak flux spectra can be questionable. We found that those GRBs that were observed by both Swift and Fermi can similarly discriminate as the complete Fermi sample. We conclude that the common observation probably did not find any trace of selection effects in the spectral behavior of GRBs.

3 Dark bursts

3.1 LSST and Gaia dark GRB rates

Gamma-ray bursts' outflow is often highly collimated into a narrow jet. If the jet's symmetry axis is not pointed towards the observer due to relativistic effects the observer can not detect radiation from this beaming cone, but later on, in the afterglow phase the relativistic beaming of the jet becomes less significant, and the jet might be visible in the optical/radio bands. These bursts are the so-called orphan GRBs. We investigated the rate of orphan-to-not-orphan bursts for the Gaia and LSST sky survey programs. Taking into account the Ly-α absorption by the interviening hydrogen systems the number of detectable afterglows is reduced. Our results suggest lower rates by ~3 times for LSST and ~9 times for Gaia.

3.2 Dark bursts at high redshift

We studied the parameters of GRBs with available spectroscopic redshift in order to be able to estimate the redshift of those GRBs without a measured one. To calculate their distances we applied two machine-learning estimator methods: random forest regressor and XGBoost. We found a significantly higher correlation between the measured and estimated redshift. It seems that both the random forest and the XGBoost methods give similarly high correlation.

Using this method we can select the distant GRBs ($z > 4$) with high significance. It seems that the distant GRBs have twice higher frequency in the population of GRBs with unknown than those having spectroscopic redshift.

4 Multivariate statistical studies

4.1 Statistical properties of GRB light curves

The light curves of Short GRB pulses exhibit triple-peaked pulse shapes similar to those found in Long GRB pulses, based on a sample of 200 BATSE TTE GRB pulses (along with a few Short GBM pulses) fitted to both the Norris et al. pulse shape and the Hakkila and Preece residual fitting function. These findings suggest that a similar physical mechanism is responsible for producing the pulses found in Long, Intermediate, and Short GRBs: this mechanism works over seven orders of magnitude in duration, represents hard-to-soft emission, and appears to be independent of the progenitor event.

We analyzed pulse properties of short gamma-ray bursts from a new catalog containing 387 BATSE time-tagged event GRBs. We classified pulse light curves using their temporal complexities, demon-

strating that short GRB pulses exhibit a range of complexities from smooth to highly variable. Unlike long/intermediate bursts, as many as 90% of short GRBs are single-pulsed. However, emission in short multipulsed bursts is coupled such that the first pulse's duration is a predictor of both the interpulse separation and subsequent pulse durations. These results strongly support the idea that external shocks produce the prompt emission seen in short GRBs. The similarities between the triple-peaked structures and spectral evolution of long, short, and intermediate GRBs then suggests that external shocks are responsible for the prompt emission observed in all GRB classes. In addition to these findings, we identified a new type of gamma-ray transient in which peak amplitudes occur at the end of the burst rather than at earlier times.

4.2 Hercules-Corona Borealis Great Wall

We got further evidence for the existence of the Hercules-Corona Borealis Great Wall. This group is displayed by GRBs at $\mathrm{z} \approx 2$ redshift. The number of GRBS having measured redshift is large enough for studying the large scale structure of the Universe. Based on newly available data we continued the study of this structure.The number of the available objects increased with 42% and the significance of the cluster continued to grow.

Several large structures, including the Sloan Great Wall, the Huge Large Quasar Group, and a large gamma-ray burst cluster referred to as the Hercules-Corona Borealis Great Wall, the later recently identified by our team, appear to exceed the maximum structural size predicted by Universal inflationary models. The scale on which the clustering occurs is disturbingly large, about $2-3$ Gpc: the underlying distribution of matter suggested by this cluster is big enough to question standard assumptions about Universal homogeneity and isotropy. The existence of very large structures such as these might necessitate cosmological model modifications.

Gamma-ray bursts are the most luminous sources found in nature. They are associated with the stellar endpoints of massive stars and are found in and near distant galaxies. Since they are viable indicators of the dense part of the Universe containing normal matter, the spatial distribution of gamma-ray bursts can serve as tracers of Universal large-scale structure.

The increasing sample size of gamma-ray bursts with known redshift provides us with the opportunity to validate or invalidate the existence of the Hercules-Corona Borealis Great Wall. Nearest-neighbour tests are used to search the larger sample for evidence of clustering and a bootstrap point-radius method is used to estimate the angular cluster size. The potential influence of angular sampling biasing is studied to determine the viability of the results.

Although, small number statistics limit our angular resolution and do not rule out the existence of adjacent and/or line-of-sight smaller structures, these structures must still clump together in order for us to see the large gamma-ray burst cluster detected here. This cluster provides support for the existence of very large-scale universal heterogeneities.

4.3 Giant GRB Ring (GGR)

Studying some statistical properties of GRBs' spatial distribution we discovered a giant ring like structure consisting of 9 GRBs, in the redshift range of $\mathrm{z} = 0.78 - 0.86$. According to the cosmological principle (CP) the large scale structure of the Universe is homogeneous and isotropic. The validity of the CP means that the size of all existing structure is less than 370 Mpc. The size of the newly discovered ring, 1720 Mpc, significantly exceeds this scale. The physical mechanism responsible for its existence is not known yet. Since the Ring is the largest regular structure known so far its discovery triggered a significant world wide response in the public media.

Studying the statistical probability of existing such rings strictly accidentally we developed an algorithm to find ring-like point patterns by chance only. Applying this algorithm to the GRB sample we identified three more ring-like point patterns. Assuming a stochastic independence of the angular and radial positions of the GRBs we simulated 1502 additional samples, altogether 542222 data points, by bootstrapping the original one. None of these data points participated in rings having similar level of compactness and regularity as the original one. Performing MCMC simulations we obtained the same number of new samples and data points as in the bootstrapping method. Among these MCMC samples only three ring-like patterns emerged with similar parameters as the original one.

We tested the independence of the angular and radial positions of the GRBs. We concluded that despite the existence of local irregularities in the GRBs' spatial distribution (e.g. the GGR) one cannot reject the Cosmological Principle, based on their spatial distribution as a whole. We pointed out the large-scale spatial pattern of the GRB activity reflects the large scale distribution of the star formation activity and does not necessarily reflect the large-scale distribution of the cosmic matter as a whole.

4.4 GGR and the Millennium simulation

The long GRBs are found more frequently in starburst galaxies. We studied the space distribution of the starburst galaxies from Millennium XXL database at $\mathrm{z} = 0.82$. First we examined the starburst distribution in the classical Millennium I, from the DeLucia (2006) database using a semi-analytical model for the genesis of the galaxies. We found a relationship between the starburst galaxies and the dark matter density distribution in Millennium I and we determined the Millennium I and Millennium XXL transformation factor. We simulated a starburst galaxies sample with Markov Chain Monte Carlo (MCMC) method where we used the Metropolis-Hastings algorithm. The connection between the large scale structures homogenous and starburst groups distribution on a defined scale were checked too.

We studied the distribution of star-forming galaxies in the classical Millennium Simulation and the Horizon Runs databases. We found a relationship between the distribution of the star-forming galaxies and the dark matter (DM), which we used as a transformation factor from the Millennium I to Millennium XXL. We simulated a star-forming galaxy sample with MCMC method, and checked the relation between structures and the distribution of star-forming groups on various scales. We concluded that above the BAO-scale we need a much more numerous sample than that of the current 407 GRBs to reveal the DM distribution. We got similar results applying our method to the Horizon Runs data. Since we previously reported two structures defined by gamma-ray bursts. One is a ring with a diameter of 1700 Mpc, displayed by 9 GRBs. The second one is even larger with a diameter of ~3000 Mpc the scale of these simulations was not enough to reveal the existence of such objects.

4.5 Exposure function of GRBs

For studying the spatial distribution of GRBs we have to know the exposure function of the experiment detected these objects. The known exposure function of GRBs can help us to reveal the large scale distribution of the Universal matter. The observed angular distribution of GRBs in the sky is influenced by the detection probability of these object at a given line of sight.

We reconstructed the exposure function by making use the kernel based methods and non parametric density estimations. It turned out that the kernel based methods are more effective in reconstructing the exposure function. We specified the exposure function for GRBs having measured redshift and with its help the angular two point correlation as well.

A strong peak was identified in the GRB two-point correlation function around 50 Mpc, with a probability of only $\mathrm{p} = 0.00996$, which originates from a pair of GRBs (GRB020819B and GRB050803), at

a distance of ~56 Mpc from each other. The very low observered GRB to supercluster ratio makes the occurrence of this doublet interesting. One should mention that the method is quite robust as the neither the empirical sky exposure function nor the empirical radial distribution function is not expected to vary significantly on this scale. Further investigation of this doublet is in progress.

5 Structure of ISM and Galactic foreground

Investigating the parameters and processes of the interstellar medium is important also in the context of GRBs. The multi-wavelength radiation of GRBs originates in the interactions of the jet with the circumstellar and interstellar medium (altogether: the intrinsic ISM) in the host galaxy. The electromagnetic radiation of any extragalactic object travels through the line of sight interstellar medium in the host galaxy, the intergalactic medium and the ISM in the Milky Way.

We analysed infared and radio data of various kinds including our own measurements, and used models exploring the fine structure of the Galactic ISM. We assume that our results are applicable also for the ISM in the GRB host galaxies.

5.1 The structure of the ISM, massive star formation

We need a better understanding of the physical processes that lead to massive star formation and the "evolution" of the interstellar medium in such regions. The LGRB progenitors are formed in, and the GRB jets are blowing into that medium that apparently has a filamentary structure, that we examined it in various scales. Accordingly, we investigated the physical processes leading to massive (GRB progenitor) star formation, the chemistry of the interstellar medium (ISM), and the ISM's filamentary structure and its relation to magnetic fields.

We studied the prototypical filamentary dark cloud TMC-1 based on Herschel SPIRE far-infrared continuum, and high S/N, high frequency resolution radio spectroscopy. We uncovered the 3D substructure with fibers, and addressed filament evolution scenarios. Further studies of Herschel FIR data sets from the Herschel Galactic Cold Cores key program were carried out extracting filaments from fields at distances $\mathrm{D} < 500$ pc. A dependence of filament parameters on the environment was found supporting an accretion-based model of filament evolution. Our results indicate that filaments acquiring a significantly massive central region may become super-critical and form stars.

We also examined a homogeneous sample of cold clumps related to the most massive filaments, i.e. infrared-dark clouds detected by the Planck satellite across the Galactic plane. Most of those contain signs of star formation. About 25% of them exceed the empirical threshold for massive star formation. Planck clumps toward the Galactic center region show higher peak column densities and higher average dust temperatures than those in the outer Galaxy. No apparent differences were found in the properties of Planck cold clumps with and without star formation.

We studied the formation of deuterated molecules in massive star forming sites at different evolutionary stages with spectroscopic measurements using the new SEPIA Band 5 receiver on APEX. Our results on the chemistry of two high-mass starless cores, two high-mass protostellar objects, and one ultracompact HII region suggest a dominance of solid state (on dust surface) chemical reactions.

We have carried out line observations of an evolved, actively star forming high column density filament G82.65-2.00. We revealed several velocity components in the field, six cold clumps close to or above the virial mass and further fragments with masses lower than or close to the virial mass, suggesting that the filament is dispersing. The velocity field potentially indicates mass accretion from the striation onto the main filament with an accretion rate of 2.23 solar mass per a million year.

With the new SEPIA Band 5 receiver on APEX, we have observed the J= $3 \rightarrow 2$ rotational lines of HDCO and D_2CO at 193 GHz and 175 GHz toward three massive star-forming regions hosting objects at different evolutionary stages: two high-mass starless cores (HMSC), two high-mass protostellar objects (HMPOs), and one ultracompact HII region (UC HII). Our observations show that the deuteration fraction of H_2CO increases from the HMSC to the HMPO phase and then sharply decreases in the latest evolutionary stage (UCHII). It may lead us to understand timescales of massive star formation.

The fragmentation of interstellar molecular clouds has been investigated with great effort by many authors. Using a modified version of the restricted three-body problem and the corresponding Jacobian integral, we gave some constraints for the motion of the fragments in a special cylindrical potential.

Based on the 850 μm dust continuum data from SCUBA-2 at James Clerk Maxwell Telescope (JCMT), we compared the overall properties of Planck Galactic Cold Clumps (PGCCs) in the lambda Orionis cloud to those of PGCCs in the Orion A and B clouds. The Orion A and B clouds are well-known active star-forming regions, while the lambda Orionis cloud has a different environment as a consequence of the interaction with a prominent OB association and a giant HII region. PGCCs in the lambda Orionis cloud have higher dust temperatures and lower values of dust emissivity spectral index than PGCCs in the Orion A and Orion B clouds. We find 119 substructures within the 40 detected PGCCs and identify them as cores. Out of a total of 119 cores, 15 cores are discovered in the lambda Orionis cloud, while 74 and 30 cores are found in the Orion A and B clouds, respectively. The cores in the lambda Orionis cloud show much lower mean values of size, column density, number density and mass compared to the cores in the Orion A and Orion B clouds. These core properties in the lambda Orionis cloud can be attributed to the photodissociation and external heating by the nearby HII region, which may prevent the PGCCs from forming gravitationally bound structures and eventually disperse them. These results support the idea of negative stellar feedback on core formation.

In order to understand the initial conditions and early evolution of star formation in a wide range of Galactic environments, we carried out an investigation of 64 Planck Galactic cold clumps (PGCCs) in the second quadrant of the Milky Way. Using the ^{13}CO and C^{18}O J $= 1 - 0$ lines and 850 μm continuum observations, we investigated cloud fragmentation and evolution associated with star formation. We extracted 468 clumps and 117 cores from the ^{13}CO line and 850 μm continuum maps, respectively. We made use of the Bayesian distance calculator and derived the distances of all 64 PGCCs. We found that in general, the mass-size plane follows a relation of $m/r \approx 1.67$. At a given scale, the masses of our objects are around 1/10 of that of typical Galactic massive star-forming regions. Analysis of the clump and core masses, virial parameters, densities, and mass-size relation suggests that the PGCCs in our sample have a low core formation efficiency (~3.0%), and most PGCCs are likely low-mass star-forming candidates. Statistical study indicates that the 850 micrometer cores are more turbulent, more optically thick, and denser than the ^{13}CO clumps for star formation candidates, suggesting that the 850 micrometer cores are likely more appropriate future star formation candidates than the ^{13}CO clumps.

Magnetic field plays a crucial role in shaping molecular clouds and regulating star formation, yet the complete information on the magnetic field is not well constrained owing to the limitations in observations. We study the magnetic field in the massive infrared dark cloud G035.39-00.33 from dust continuum polarization observations at 850 μm with SCUBA-2/POL-2 at JCMT for the first time. The magnetic field tends to be perpendicular to the densest part of the main filament, whereas it has a less defined relative orientation in the rest of the structure, where it tends to be parallel to some diffuse regions. A mean plane-of-the-sky magnetic field strength of approx. 50 microgauss for the main filament is obtained using the Davis-Chandrasekhar-Fermi method. Based on ^{13}CO $(1 - 0)$ line observations, we suggest a formation scenario of the main filament due to large-scale (~10 pc) cloud-cloud collision. Using additional NH3 line data, we estimate that it will be gravitationally unstable if it is only supported by thermal pressure and turbulence. The northern part of the main filament, however, can be stabilized by a

modest additional support from the local magnetic field. The middle and southern parts are likely unstable even if the magnetic field support is taken into account. We claim that the clumps in the main filament may be supported by turbulence and magnetic fields against gravitational collapse. Finally, we identified for the first time a massive (200 solar mass), collapsing starless clump candidate, "c8," in G035.39-00.33. The magnetic field surrounding "c8" is likely pinched, hinting at an accretion flow along the filament.

5.2 Galactic foreground of extragalactic objects

The X-ray afterglow radiation of GRBs travels through the line of sight extragalactic, intergalactic, and the interstellar medium in the Milky Way. We examined the effect of foreground hydrogen column density on the penetrating X-ray emission.

We used far infrared imaging photometry data to resolve the fine structure and density of the Galactic foreground interstellar medium (ISM) in the direction of GRBs. This resulted in an increase in the precision of calculating the column density of intrinsic ISM at the GRBs in their host galaxies.

One important consequence is that the filing factor of the high column density gas is low. So a low resolution observation will typically underestimate the foreground extinction. Another important result is that all except one of the so called non-enveloped GRBs looked normally embedded into intrinsic ISM after the corrected foreground values were applied.

5.3 Paper in preparation

ATCA HI 21cm observations of the Galactic foreground: A common practice to correct for the Galactic foreground is to use neutral hydrogen data from the Leiden/Argentina/Bonn (LAB) survey. However, the poor spatial resolution of the single dish HI 21cm data may have a significant effect on the derived column densities. To investigate this, we performed high-resolution 21cm observations with the Australia Telescope Compact Array (ATCA) towards 4 GRBs. We processed the interferometric ATCA data together with single dish data from the Galactic All Sky Survey (GASS) and derive new Galactic hydrogen column density values towards the GRBs. The HI 21 cm optical depth was also derived using the absorption seen towards nearby extragalactic continuum point sources. We combined these new estimates on the Galactic foreground hydrogen column density with X-ray spectra from Swift XRT to derive new intrinsic hydrogen column density values for the GRB host galaxies. We plan to publish the resulted corrected foreground and recalculated intrinsic column densities together with maps of the Galactic foreground in the Monthly Notices of the Royal Astronomical Society (MNRAS).

5.4 Measurements in the queue

Effelsberg-100m observations: We have running observations of the OH 18cm lines of the Galactic foreground in the direction of GRB sources near the Galactic mid-plane. Our goal is to estimate the column density of molecular hydrogen not traced by CO observations in the same directions. That will be then compared to FIR observations of the Galacic dust, a common basis of extinction estimates.

CO radio spectral line observations: Observations of the CO(2-1) 1.3cm line were planned and partly performed using the Nobeyama-1.75m radiotelescope of the Osaka Prefecture University. The observations are to be continued this winter.

6 Star formation and ISM in GRB host galaxies

Long GRBs occur in star forming galaxies, but the link between the properties of the host galaxies and the occurrence of GRBs is still unclear. Also it is a matter of discussion how well the GRB hosts and quasars can trace the distribution of matter in the universe. We investigated various types of galaxies also at cosmological distances as steps towards a clarification.

6.1 Star-forming galaxies

Star-forming galaxies appear as FIR and sub-mm emitters. The point sources in the Bright Source Catalogue (BSC) of the AKARI Far–Infrared Surveyor (FIS) were classified based on their far–IR and mid–IR fluxes and colours using Quadratic Discriminant Analysis method (QDA) and Support Vector Machines (SVM). The reliability of our results on 2MASS and AKARI data show that we can successfully separate galactic and extragalactic point sources in the multidimensional space of fluxes and colours. However, differentiating among the extragalactic sub–types needs further information.

We contributed to the creation of the point source catalogue of the Herschel Spectral and Photometric Imaging Receiver (SPIRE) radiometer from a total of 6878 unmodified SPIRE scan map observations. This catalog is aimed primarily at the extragalactic community with 1,693,718 sources. Applying a sophisticated statistical method, the support vector machine to analyse point source photometry data (WISE, 2MASS), we classified millions of objects into classes: extragalactic sources, main-sequence stars, evolved stars and sources related to the interstellar medium.

The European Large-Area ISO Survey (ELAIS) N1 field is one of the extragalactic windows where the lack of the Galactic ISM allows us to analyze the unbiased FIR properties of extragalactic objects. The field was observed by the ISO and Spitzer infrared space telescopes, and followed-up with a number of ground base measurements in various wavelength bands. It was investigated in more details recently based on deep Herschel observations by the HerMES key project. We present a survey of the field covering a larger area than HerMES. We provide accurate 250, 350, and 500 micrometer flux densities for about 8000 point sources using the latest Herschel analysis and calibration procedures. Based on SDSS spectroscopic and SWIRE photometric data our sample has approximately 4000 and 4500 galaxies with $0.2 < \mathrm{z} < 0.5$ and $\mathrm{z} > 0.5$ redshifts, respectively. The new flux densities are crucial limiting the star-forming activity of galaxies outside the Local Universe, and especially for the ones at $\mathrm{z} > 0.5$, as it is demonstrated in the star-forming galaxy 2MASS J16072472+5412119.

6.2 PAHs in star-forming galaxies

Polycyclic aromatic hydrocarbons (PAHs) are excited by the UV photons of young stars, but they are dissociated by strong UV radiation in starbursts. Therefore their emission can be used as a star formation tracer in main sequence galaxies. The relationship of star formation and PAH content was examined in a variety of galaxies. Important mid-IR bands of PAHs are in the wavelength range covered by AKARI, we analysed such measurements. Several parameters of the galaxies were estimated, e.g. star formation rate (SFR), stellar mass and the fraction of PAHs compared to dust mass (q_{PAH}), and the relations between these parameters were examined.

The majority of the sample is near the main sequence of star forming galaxies. We compared the q_{PAH} values with the known relations of the PAH luminosities. The q_{PAH} values do not follow the same trends, and they only slightly correlate with the PAH luminosities.

This paper has been accepted for publication by the Publication of the Astronomical Society of Japan (PASJ) and will appear in early 2019. May we note here that the first author of the paper is Tímea Kovács,

an MSc student, who started this study as a student research project (TDK) about 1 year ago.

6.3 AGNs

We compiled a photometric catalogue of the complete sample of all known AGNs at $z \geq 4$. The continuously updated list now contains nearly 2600 objects with known spectroscopic redshifts, optical magnitudes, and auxiliary information about observations at other wavebands.

6.4 Paper in preparation

Herschel observations and parameters of GRB host galaxies: We reprocessed and re-evaluated all the Herschel measurements of GRB host galaxies. The FIR fluxes and upper limits were especially important modelling the spectral energy distributions (SED). The SEDs were modelled using the CIGALE package. The new FIR data helped us to constrain the star forming rates, and the mass of ISM. The star forming rates of the studied GRB host galaxies were in general higher than the typical values for other star forming galaxies with similar masses and at similar redshifts. We plan to publish the resulted corrected FIR fluxes, the derived host galaxy parameters, and the observed relations among those in the Monthly Notices of the Royal Astronomical Society (MNRAS).

6.5 Measurements in the queue

Exploring the cold interstellar medium content of GRB host galaxies we planned CO spectral line, and mm continuum observations using interferometer systems. The proposals were prepared and submitted in collaboration with our foreign partners.

Karl Jansky Very Large Array observations: Although we were granted Jansky Very Large Array (VLA) observing time about 1 year ago, our measurements haven't been executed yet due to technical issues at VLA (a major electrical infrastructure upgrade). We expect to get CO($J = 1 - 0$) spectral line data on the host galaxy of GRB080207 at a redshift of $z = 2$ in late November early December 2018. We note that we already detected the CO($J = 3 - 2$) spectral line for that galaxy with a high enough S/N using the IRAM PdBI interferometer system.

NOEMA observations: In order to better constrain the SEDs of GRB host galaxies we planned mm continuum observations with the NOEMA interferometer system. Our proplsal has been accepted and we are waiting for the scheduling of our measurements.