Annual Report 2020

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and Tartu Observatory cosmology group

1 Research

In this Section the work is described I made together with my collaborates. The work is described using Abstracts of papers and is divided into sections.

1.1 Fundamental problems of the cosmological paradigm

Einasto (2020a): We study biasing as a physical phenomenon by analysing power spectra (PS) and correlation functions (CF) of simulated galaxy samples and dark matter (DM) samples. We apply an algorithm based on the local densities of particles, ρ_0, to form populations of simulated galaxies, using particles with $\rho \geq \rho_0$. We calculate two-point CF of projected (2D) and spatial (3D) density fields of simulated galaxies for various particle-density limits ρ_0. We compare 3D and 2D CFs; in 2D case we use samples of various thickness to find the dependence of 2D CFs on thickness of samples. Dominant elements of the cosmic web are clusters and filaments, separated by voids filling most of the volume. In individual 2D sheets positions of clusters and filaments do not coincide. As a result, in projection clusters and filaments fill in 2D voids. This leads to the decrease of amplitudes of CFs in projection. For this reason amplitudes of 2D CFs are lower than amplitudes of 3D CFs, the difference is the larger, the thicker are 2D samples. Using PS and CFs of simulated galaxies and DM we estimate the bias factor for L^* galaxies, $b^* = 1.85 \pm 0.15$.

Einasto et al. (2020b): Aims: Our goal is to determine how the spatial correlation function of galaxies describes biasing and fractal properties of the cosmic web. Methods: We calculated spatial correlation functions of galaxies, $\xi(r)$, structure functions, $g(r) = 1 + \xi(r)$, gradient functions, $\gamma(r) = d\log g(r)/d\log r$, and fractal dimension functions, $D(r) = 3 + \gamma(r)$, using dark matter particles of the biased Λ cold dark matter (CDM) simulation, observed galaxies of the Sloan Digital Sky Survey (SDSS), and simulated galaxies of the Millennium and EAGLE simulations. We analysed how these functions describe fractal and biasing properties of the cosmic web. Results: The correlation functions of the biased LCDM model samples at small distances (particle and galaxy separations), $r \leq 2.25\ h^{-1}$ Mpc, describe the distribution of matter inside dark matter halos. In real and simulated galaxy samples, only the brightest galaxies in clusters are visible, and the transition from clusters to filaments occurs at a distance $r \approx 0.8 - 1.5\ h^{-1}$ Mpc. At larger separations, the correlation functions describe the distribution of matter and galaxies in the whole cosmic web. The effective fractal dimension of the cosmic web is a continuous function of the distance (separation). Real and simulated galaxies of low luminosity, $M_r \geq -19$, have almost identical correlation lengths and amplitudes, indicating that dwarf galaxies are satellites of brighter galaxies, and do not form a smooth population in voids. Conclusions: The combination of several physical processes (e.g. the formation of halos along the caustics of particle trajectories and the phase synchronisation of density perturbations on various scales) transforms the initial random density field to the current highly non-random density field. Galaxy formation is suppressed in voids, which increases the amplitudes of correlation functions and power spectra of galaxies, and increases the large-scale bias parameter. The combined evidence leads to the large-scale bias parameter of L^* galaxies the value $b^* = 1.85 \pm 0.15$. We find $r_0(L^*) = 7.20 \pm 0.19$ for the correlation length of L^* galaxies.

Einasto et al. (2020d): We investigate the evolution of superclusters and supercluster cocoons (basins of attraction), and the influence of cosmological parameters to the evolution. We perform numerical simulations of the evolution of the cosmic web for different cosmological models: the LCDM model with a conventional value of the dark energy (DE) density, the open model OCDM with no DE, the standard SCDM model with no DE, and the Hyper-DE HCDM model with an enhanced DE density value. We find ensembles of superclusters of these models for five evolutionary stages, corresponding to the present epoch $z = 0$, and to redshifts $z = 1, 3, 10, 30$. We use diameters of the largest superclusters and the number of superclusters as percolation functions to describe properties of the ensemble of superclusters in the cosmic web. We analyse the size and mass distribution of superclusters in models and in real Sloan Digital Sky Survey (SDSS) based samples. In all models numbers and volumes of supercluster cocoons are independent on cosmological epochs. Supercluster masses increase with time, and geometrical sizes in comoving coordinates decrease with time, for all models. LCDM, OCDM and HCDM models have almost similar percolation parameters. This suggests that the essential parameter, which defines the evolution of superclusters, is the matter density. The DE density influences the growth of the amplitude of density perturbations, and the growth of masses of superclusters, albeit significantly less strongly. The HCDM model has the largest speed of the growth of the amplitude of density fluctuations, and the largest growth of supercluster masses during the evolution. Geometrical diameters and numbers of HCDM superclusters at high threshold densities are larger than for LCDM and OCDM superclusters. SCDM model has about two times more superclusters than other models; SCDM superclusters have smaller diameters and masses.

Einasto et al. (2020a): Our goal is to find the relation between the two-point correlation functions of the projected and spatial density fields of galaxies, and their influence to biasing, fractal and other geometrical properties of the cosmic web. Using spatial (3D) and projected (2D) density fields we calculate 3D and 2D correlation functions of galaxies, $\xi(r)$, structure functions, $g(r) = 1 + \xi(r)$, and fractal functions, $\gamma(r) = d\log g(r)/d\log r$, for a biased Λ cold dark matter (CDM) simulation. We analyse how these functions describe biasing, fractal and other properties of the cosmic web. We compare the correlation functions of spatial and projected density fields as descriptors of the cosmic web. Dominant elements of the cosmic web are clusters and filaments, separated by voids filling most of the volume. In individual 2D sheets the positions of clusters and filament do not coincide. As a result, in projection clusters and filaments fill in 2D voids. This leads to the decrease of amplitudes of correlation functions (and power spectra) in projection. For this reason amplitudes of 2D correlation functions are lower than amplitudes of 3D correlation functions, the difference is the larger, the thicker are 2D samples. Spatial correlation functions of galaxies contain valuable information on geometrical properties of the cosmic web, not available in angular correlation functions. 2D correlation functions do not contain information on voids in 3D density field, thus 3D correlation functions cannot be calculated from 2D correlation functions.

Einasto et al. (2020c): We perform numerical simulations of the evolution of the cosmic web for the conventional ΛCDM model in box sizes $L_0 = 256, 512, 1024\ \ h^{-1}$ Mpc. We calculate models, corresponding to the present epoch $z = 0$, and to redshifts $z = 1, 3, 5, 10, 30$. We calculate density fields with various smoothing levels to find the dependence of the density field on smoothing. We calculate PDF and its moments – variance, skewness and kurtosis. The dimensionless skewness S and the dimensionless kurtosis K characterise symmetry and flatness properties of the 1-point PDF of the cosmic web. Relations $S = S_3\sigma$, and $K = S_4\sigma^2$ are now tested in standard deviation σ range, $0.015 \le \sigma \le 10$, and in redshift z range $0 \le z \le 30$. Reduced skewness S_3 and reduced kurtosis S_4 described in log-log format. Data show that these relations can be extrapolated to earlier redshifts z, and to smaller σ, as well as to smaller and larger smoothing lengths R. Reduced parameters depend on basic parameters of models. The reduced skewness: $S_3 = f_3(R)+g_3(z)\sigma^2$, and the reduced kurtosis: $S_4 = f_4(R)+g_4(z)\sigma^2$, where $f_3(R)$ and $f_4(R)$ are parameters, depending on the smoothing length, R, and $g_3(z)$ and $g_4(z)$ are parameters, depending on the evolutionary epoch z. The lower bound of the amplitude parameters are, $f_3(R) \approx 3.5$ for reduced skewness, and $f_4(R) \approx 16$ for reduced kurtosis, for large smoothing lengths, $R \approx 32\ h^{-1}$ Mpc. With decreasing smoothing length R the skewness and kurtosis values for given redshift z turn upwards.

2 Conferences and popular talks

In January 18 I had a talk in Tartu "Vanemuine Society" *Universe and us*.

In September 7 — 11 The Fourth Zeldovich virtual meeting was hold. I has a talk on topic *The biasing phenomenon* (Einasto, 2020a). Maret Einasto had a talk (Einasto, 2020b).

In October 16 the defence of a PhD thesis by P. Ganeshaiah-Veena (Ganeshaiah Veena et al., 2020) was hold, I served as one of reviewers.

3 Scientific organisations, awards

I am member of the International Astronomical Union (1961), Estonian Academy of Sciences (1981), American Astronomical Society (1981), European Astronomical Society (1990), Academia Europaea (1990), Royal Astronomical Society (1994).

I have Estonian Science Prizes (1982, 1998, 2003, 2007), Gauss Professor of the Göttingen University (1993), The Estonian Order of the National Coat of Arms (1998), Marcel Grossmann Award (2009), honorary Doctor of Tartu University (2010), Viktor Ambartsumian International Prize (2012), Doctor Honoris Causa degree of the Turku University (2013), Gruber International Cosmology Award (2014), Estonian Academy of Sciences Harald Keres medal (2019), Tartu University great medal (2019)..

4 Research – Tartu Observatory cosmology group

In this Section the work is described done in Tartu Observatory cosmology group, in addition to the work described in Section 1. This overview is based on abstracts written by authors of respective papers.

4.1 Collection of new data

Tempel et al. (2020b): Large multiobject spectroscopic surveys require automated algorithms to optimize their observing strategy. One of the most ambitious upcoming spectroscopic surveys is the 4MOST survey. The 4MOST survey facility is a fibre-fed spectroscopic instrument on the VISTA telescope with a large enough field of view to survey a large fraction of the southern sky within a few years. Several Galactic and extragalactic surveys will be carried out simultaneously, so the combined target density will strongly vary. In this paper, we describe a new tiling algorithm that can naturally deal with the large target density variations on the sky and which automatically handles the different exposure times of targets. The tiling pattern is modelled as a marked point process, which is characterized by a probability density that integrates the requirements imposed by the 4MOST survey. The optimal tilling pattern with respect to the defined model is estimated by the tiles configuration that maximizes the proposed probability density. In order to achieve this maximization a simulated annealing algorithm is implemented. The algorithm automatically finds an optimal tiling pattern and assigns a tentative sky brightness condition and exposure time for each tile, while minimizing the total execution time that is needed to observe the list of targets in the combined input catalogue of all surveys. Hence, the algorithm maximizes the long-term observing efficiency and provides an optimal tiling solution for the survey. While designed for the 4MOST survey, the algorithm is flexible and can with simple modifications be applied to any other multiobject spectroscopic survey.

Baqui et al. (2020): Future astrophysical surveys such as J-PAS will produce very large datasets, which will require the deployment of accurate and efficient Machine Learning (ML) methods. In this work, we analyze the miniJPAS survey, which observed about 1 deg2 of the AEGIS field with 56 narrow-band filters and 4 ugri broad-band filters. We discuss the classification of miniJPAS sources into extended (galaxies) and point-like (e.g. stars) objects, a necessary step for the subsequent scientific analyses. We aim at developing an ML classifier that is complementary to traditional tools based on explicit modeling. In order to train and test our classifiers, we crossmatched the miniJPAS dataset with SDSS and HSC-SSP data. We trained and tested 6 different ML algorithms on the two crossmatched catalogs. As input for the ML algorithms we use the magnitudes from the 60 filters together with their errors, with and without the morphological parameters. We also use the mean PSF in the r detection band for each pointing. We find that the RF and ERT algorithms perform best in all scenarios. When analyzing the full magnitude range of $15 < r < 23.5$ we find AUC=0.957 with RF when using only photometric information, and AUC=0.986 with ERT when using photometric and morphological information. Regarding feature importance, when using morphological parameters, FWHM is the most important feature. When using photometric information only, we observe that broad bands are not necessarily more important than narrow bands, and errors are as important as the measurements. ML algorithms can compete with traditional star/galaxy classifiers, outperforming the latter at fainter magnitudes ($r > 21$). We use our best classifiers, with and without morphology, in order to produce a value added catalog available at https://j-pas.org/datareleases .

Bonoli et al. (2020): The Javalambre-Physics of the Accelerating Universe Astrophysical Survey (J-PAS) will soon start to scan thousands of square degrees of the northern extragalactic sky with a unique set of 56 optical filters from a dedicated 2.55 m telescope, JST, at the Javalambre Astrophysical Observatory. Before the arrival of the final instrument (a 1.2 Gpixels, 4.2deg 2 field-of-view camera), the JST was equipped with an interim camera (JPAS-Pathfinder), composed of one CCD with a 0.3deg 2 field-of-view and resolution of 0.23 arcsec pixel^{-1}. To demonstrate the scientific potential of J-PAS, with the JPAS-Pathfinder camera we carried out a survey on the AEGIS field (along the Extended Groth Strip), dubbed miniJPAS. We observed a total of 1 deg 2 , with the 56 J-PAS filters, which include 54 narrow band (NB, FWHM$\sim$145 Angstrom) and two broader filters extending to the UV and the near-infrared, complemented by the u,g,r,i SDSS broad band (BB) filters. In this paper we present the miniJPAS data set, the details of the catalogues and data access, and illustrate the scientific potential of our multi-band data. The data surpass the target depths originally planned for J-PAS, reaching magAB mag A B between ~ 22 and 23.5 for the NB filters and up to 24 for the BB filters (5σ in a 3 arcsec aperture). The miniJPAS primary catalogue contains more than 64,000 sources extracted in the r detection band with forced photometry in all other bands. We estimate the catalogue to be complete up to $r = 23.6$ for point-like sources and up to $r = 22.7$ for extended sources. Photometric redshifts reach subpercent precision for all sources up to $r = 22.5$, and a precision of ~ 0.3 % for about half of the sample.

Tempel et al. (2020a): Context. Several new multi-object spectrographs are currently planned or under construction that are capable of observing thousands of Galactic and extragalactic objects simultaneously. Aims: In this paper we present a probabilistic fibre-to-target assignment algorithm that takes spectrograph targeting constraints into account and is capable of dealing with multiple concurrent surveys. We present this algorithm using the 4-m Multi-Object Spectroscopic Telescope (4MOST) as an example. Methods: The key idea of the proposed algorithm is to assign probabilities to fibre-target pairs. The assignment of probabilities takes the fibre positioner's capabilities and constraints into account. Additionally, these probabilities include requirements from surveys and take the required exposure time, number density variation, and angular clustering of targets across each survey into account. The main advantage of a probabilistic approach is that it allows for accurate and easy computation of the target selection function for the different surveys, which involves determining the probability of observing a target, given an input catalogue. Results: The probabilistic fibre-to-target assignment allows us to achieve maximally uniform completeness within a single field of view. The proposed algorithm maximises the fraction of successfully observed targets whilst minimising the selection bias as a function of exposure time. In the case of several concurrent surveys, the algorithm maximally satisfies the scientific requirements of each survey and no specific survey is penalised or prioritised. Conclusions: The algorithm presented is a proposed solution for the 4MOST project that allows for an unbiased targeting of many simultaneous surveys. With some modifications, the algorithm may also be applied to other multi-object spectroscopic surveys.

Comparat et al. (2020): The eROSITA X-ray telescope on board the Spectrum-Roentgen-Gamma (SRG) mission will measure the position and properties of about 100,000 clusters of galaxies and 3 million active galactic nuclei over the full sky. To study the statistical properties of this ongoing survey, it is key to estimate the selection function accurately. We create a set of full sky light-cones using the MultiDark and UNIT dark matter only N-body simulations. We present a novel method to predict the X-ray emission of galaxy clusters. Given a set of dark matter halo properties (mass, redshift, ellipticity, offset parameter), we construct an X-ray emissivity profile and image for each halo in the light-cone. We follow the eROSITA scanning strategy to produce a list of X-ray photons on the full sky. We predict scaling relations for the model clusters, which are in good agreement with the literature. The predicted number density of clusters as a function of flux also agrees with previous measurements. Finally, we obtain a scatter of 0.21 (0.07, 0.25) for the X-ray luminosity – mass (temperature – mass, luminosity – temperature) model scaling relations. We provide catalogues with the model photons emitted by clusters and active galactic nuclei. These catalogues will aid the eROSITA end to end simulation flow analysis and in particular the source detection process and cataloguing methods.

4.2 Early Universe

Adak et al. (2020): The primary source of systematic uncertainty in the quest for the B-mode polarization of the Cosmic Microwave Background (CMB) introduced by primordial gravitational waves is polarized thermal emission from Galactic dust. Therefore, accurate characterization and separation of the polarized thermal dust emission is an essential step in distinguishing such a faint CMB B-mode signal. We provide a modelling framework to simulate polarized thermal dust emission based on the model described in Ghosh et al. (2017, A&A, 601, A71), making use of both the Planck dust and Effelsberg-Bonn HI surveys over the northern Galactic cap. Our seven-parameter dust model, incorporating both HI gas in three different column density templates as a proxy for spatially variable dust intensity and a phenomenological model of Galactic magnetic field, is able to reproduce both one- and two-point statistics of the observed dust polarization maps seen by Planck at 353 GHz over a selected low-column density region in the northern Galactic cap. This work has important applications in assessing the accuracy of component separation methods and in quantifying the confidence level of separating polarized Galactic emission and the CMB B-mode signal, as is needed for ongoing and future CMB missions.

Barrena et al. (2020): We report new galaxy clusters previously unknown included in the first Planck Sunyaev-Zeldovich (SZ) sources catalogue, the PSZ1. The results presented here were achieved during the second year of a two-year observational programme, the ITP13, developed at the Roque de los Muchachos Observatory (La Palma, Spain). Using the 2.5 m Isaac Newton telescope, the 3.5 m Telescopio Nazionale Galileo, the 4.2 m William Herschel telescope and the 10.4 m Gran Telescopio Canarias we characterised 75 SZ sources with low SZ significance, SZ $S/N < 5.32$. We performed deep optical imaging and spectroscopy in order to associate actual galaxy clusters with the SZ Planck source. We adopted robust criteria, based on the 2D spatial distribution, richness, and velocity dispersions to confirm actual optical counterparts up to $z < 0.85$. The selected systems are confirmed only if they are well aligned with respect to the PSZ1 coordinate and show high richness and high velocity dispersion. In addition, we also inspected the Compton y-maps and SZ significance in order to identify unrealistic detections. Following this procedure, we identify 26 cluster counterparts associated with the SZ emission, which means that only about 35% of the clusters considered in this low S/N PSZ1 subsample are validated. Forty-nine SZ sources (65% of this PSZ1 subset) remain unconfirmed. At the end of the ITP13 observational programme, we have studied 256 SZ sources with $Dec \geq -15°$ (212 of them completely unknown), finding optical counterparts for 152 SZ sources. The ITP13 validation programme has allowed us to update the PSZ1 purity, which is now more refined, increasing from 72% to 83% in the low SZ S/N regime. Our results are consistent with the predicted purity curve for the full PSZ1 catalogue and with the expected fraction of false detections caused by the non-Gaussian noise of foreground signals. We find a strong correlation between the number of unconfirmed sources and the thermal emission of diffuse galactic dust at 857 GHz, thus increasing the fraction of false Planck SZ detections at low galactic latitudes.

Hütsi et al. (2020): We analyse the LIGO-Virgo data, including the recently released GWTC-2 dataset, to test a hypothesis that the data contains more than one population of black holes. We perform a maximum likelihood analysis including a population of astrophysical black holes with a truncated power-law mass function whose merger rate follows from star formation rate, and a population of primordial black holes for which we consider log-normal and critical collapse mass functions. We find that primordial black holes alone are strongly disfavoured by the data, while the best fit is obtained for the template combining astrophysical and primordial merger rates. Alternatively, the data may hint towards two different astrophysical black hole populations. We also update the constraints on primordial black hole abundance from LIGO-Virgo observations finding that in the $2 - 400 M_{\odot}$ mass range, they must comprise less than 0.2% of dark matter.

Benito et al. (2020): We study how the indirect observation of dark matter substructures in the Milky Way, using recent stellar stream studies, translates into constraints for different dark matter models. Particularly, we use the measured number of dark subhalos in the mass range $10^7 - 10^9 M_{\odot}$ to constrain modifications of the subhalo mass function compared to the cold dark matter scenario. We obtain the lower bounds $mWDM > 3.2$ keV and $mFDM > 5.2 \times 10^{-21}$ eV on the warm dark matter and fuzzy dark matter particle mass, respectively. When dark matter is coupled to a dark radiation bath, we find that kinetic decoupling must take place at temperatures higher than $Tkd > 0.7$ keV . We also discuss future prospects of stellar stream observations.

4.3 Cosmic web: structure of superclusters

Einasto (2020b): The largest galaxy systems in the cosmic web are superclusters, overdensity regions of galaxies, groups, clusters, and filaments. Low-density regions around superclusters are called basins of attraction or cocoons. In my talk I discuss the properties of galaxies, groups, and filaments in the A2142 supercluster and its cocoon at redshift $z \approx 0.09$. Cocoon boundaries are determined by the lowest density regions around the supercluster. We analyse the structure, dynamical state, connectivity, and galaxy content of the supercluster, and its high density core with the cluster A2142. We show that the main body of the supercluster is collapsing, and long filaments which surround the supercluster are detached from it. Galaxies with very old stellar populations lie not only in the central parts of clusters and groups in the supercluster, but also in the poorest groups in the cocoon.

Einasto et al. (2020e): Context. Superclusters of galaxies and their surrounding low-density regions (cocoons) represent dynamically evolving environments in which galaxies and their systems form and evolve. While evolutionary processes of galaxies in dense environments are extensively studied at present, galaxy evolution in low-density regions has received less attention. Aims: We study the properties, connectivity, and galaxy content of groups and filaments in the A2142 supercluster (SCl A2142) cocoon to understand the evolution of the supercluster with its surrounding structures and the galaxies within them. Methods: We calculated the luminosity-density field of SDSS galaxies and traced the SCl A2142 cocoon boundaries by the lowest luminosity-density regions that separate SCl A2142 from other superclusters. We determined galaxy filaments and groups in the cocoon and analysed the connectivity of groups, the high density core (HDC) of the supercluster, and the whole of the supercluster. We compared the distribution and properties of galaxies with different star-formation properties in the supercluster and in the cocoon. Results: The supercluster A2142 and the long filament that is connected to it forms the longest straight structure in the Universe detected so far, with a length of approximately 75 h^{-1} Mpc. The connectivity of the cluster A2142 and the whole supercluster is $C = 6 - 7$; poor groups exhibit $C = 1 - 2$. Long filaments around the supercluster's main body are detached from it at the turnaround region. Among various local and global environmental trends with regard to the properties of galaxies and groups, we find that galaxies with very old stellar populations lie in systems across a wide range of richness from the richest cluster to poorest groups and single galaxies. They lie even at local densities as low as $D1 < 1$ in the cocoon and up to $D1 > 800$ in the supercluster. Recently quenched galaxies lie in the cocoon mainly in one region and their properties are different in the cocoon and in the supercluster. The star-formation properties of single galaxies are similar across all environments. Conclusions: The collapsing main body of SCl A2142 with the detached long filaments near it are evidence of an important epoch in the supercluster evolution. There is a need for further studies to explore possible reasons behind the similarities between galaxies with very old stellar populations in extremely different environments, as well as mechanisms for galaxy quenching at very low densities. The presence of long, straight structures in the cosmic web may serve as a test for cosmological models.

4.4 Structure of clusters of galaxies

Rong et al. (2020): We find that the minor axes of the ultra-diffuse galaxies (UDGs) in Abell 2634 tend to be aligned with the major axis of the central dominant galaxy, at a ≥ 95 per cent confidence level. This alignment is produced by the bright UDGs with the absolute magnitudes

$Mr < -15.3$ mag, and outer-region UDGs with $R > 0.5$R200. The alignment signal implies that these bright, outer-region UDGs are very likely to acquire their angular momenta from the vortices around the large-scale filament before they were accreted into A2634, and form their extended stellar bodies outside of the cluster; in this scenario, the orientations of their primordial angular momenta, which are roughly shown by their minor axes on the images, should tend to be parallel to the elongation of the large-scale filament. When these UDGs fell into the unrelaxed cluster A2634 along the filament, they could still preserve their primordial alignment signal before violent relaxation and encounters. These bright, outer-region UDGs in A2634 are very unlikely to be the descendants of the high-surface-brightness dwarf progenitors under tidal interactions with the central dominant galaxy in the cluster environment. Our results indicate that the primordial alignment could be a useful probe of the origin of UDGs in large-scale structures.

Deshev et al. (2020): Aims: We qualitatively assess and map the relative contribution of pre-processing and cluster related processes to the build-up of A963, a massive cluster at z = 0.2 showing an unusually high fraction of star forming galaxies in its interior. Methods: We use Voronoi binning of positions of cluster members on the plane of the sky in order to map the 2D variations of galaxy properties in the centre and infall region of A963. We map four galaxy parameters (fraction of star forming galaxies, specific star formation rate, H I deficiency and age of the stellar population) based on full SED fitting, 21 cm imaging and optical spectroscopy. Results: We find an extended region dominated by passive galaxies along a north-south axis crossing the cluster centre, possibly associated with known filaments of the large-scale structure. There are signs that the passive galaxies in this region were quenched long before their arrival in the vicinity of the cluster. Contrary to that, to the east and west of the cluster centre lie regions of recent accretion dominated by gas rich, actively star forming galaxies not associated with any substructure or filament. The few passive galaxies in this region appear to be recently quenched, and some gas rich galaxies show signs of ongoing ram-pressure stripping. We report the first tentative observations at 21 cm of ongoing ram-pressure stripping at $z = 0.2$, as well as observed inflow of low-entropy gas into the cluster along filaments of the large-scale structure. Conclusions: The observed galaxy content of A963 is a result of strongly anisotropic accretion of galaxies with different properties. Gas rich, star forming galaxies are being accreted from the east and west of the cluster and these galaxies are being quenched at $r < R200$, likely by ram-pressure stripping. The bulk of the accretion onto the cluster, containing multiple groups, happens along the north-south axis and brings mostly passive galaxies, likely quenched before entering A963.

4.5 Cosmic web: structure of filaments

Kuutma et al. (2020): Context. The cosmic web, a complex network of galaxy groups and clusters connected by filaments, is a dynamical environment in which galaxies form and evolve. However, the impact of cosmic filaments on the properties of galaxies is difficult to study because of the much more influential local (galaxy-group scale) environment. Aims: The aim of this paper is to investigate the dependence of intrinsic galaxy properties on distance to the nearest cosmic web filament, using a sample of galaxies for which the local environment is easily assessable. Methods: Our study is based on a volume-limited galaxy sample with $Mr \leq -19$ mag, drawn from the SDSS DR12. We chose brightest group galaxies (BGGs) in groups with two to six members as our probes of the impact of filamentary environment because their local environment can be determined more accurately. We use the Bisous marked point process method to detect cosmic-web filaments with radii of $0.5 - 1.0$ Mpc and measure the perpendicular filament spine distance (Dfil) for the BGGs. We limit our study to Dfil values up to 4 Mpc. We use the luminosity density field as a tracer of the local environment. To achieve uniformity of the sample and to reduce potential biases we only consider filaments longer than 5 Mpc. Our final sample contains 1427 BGGs. Results: We note slight deviations between the galaxy populations inside and outside the filament radius in terms of stellar mass, colour, the 4000 Å break, specific star formation rates, and morphologies. However, all these differences remain below 95% confidence and are negligible compared to the effects arising from local environment density. Conclusions: Within a 4 Mpc radius of the filament axes, the effect of filaments on BGGs is marginal. The local environment is the main factor in determining BGG properties.

Tempel (2020): We investigate the alignment of galaxies and haloes relative to cosmic web filaments using the P-Millennium cosmological simulation and the EAGLE hydrodynamical simulation (Ganeshaiah Veena et al. 2018,2019). EAGLE haloes have an identical spin alignment with filaments as their counterparts in dark-matter-only simulations: a complex mass-dependent trend with low-mass haloes spinning preferentially parallel to and high-mass haloes spinning preferentially perpendicular to filaments. When splitting by morphology, we find that elliptical galaxies show a stronger orthogonal spin-filament alignment than spiral galaxies of similar mass. The same is true of their host haloes. This supports the observational findings based on SDSS (Tempel et al. 2013, Tempel & Libeskind 2013). Due to the misalignment between galaxy shape and spin, galaxy minor axes are oriented differently with filaments than galaxy spins. We find that the galaxies whose minor axis is perpendicular to a filament are much better aligned with their host haloes. This suggests that many of the same physical processes determine both the galaxy-filament and the galaxy-halo alignments. Next generation surveys (e.g. 4MOST WAVES survey) will provide an unprecedented data set to test various angular momentum acquisition theories.

Ganeshaiah Veena et al. (2020): We explore the evolution of halo spins in the cosmic web using a very large sample of dark matter haloes in the ΛCDM Planck-Millennium N-body simulation. We use the NEXUS+ multiscale formalism to identify the hierarchy of filaments and sheets of the cosmic web at several redshifts. We find that at all times the magnitude of halo spins correlates with the web environment, being largest in filaments, and, for the first time, we show that it also correlates with filament thickness as well as the angle between spin-orientation and the spine of the host filament. For example, massive haloes in thick filaments spin faster than their counterparts in thin filaments, while for low-mass haloes the reverse is true. We also have studied the evolution of alignment between halo spin orientations and the preferential axes of filaments and sheets. The alignment varies with halo mass, with the spins of low-mass haloes being predominantly along the filament spine, while those of high-mass haloes being predominantly perpendicular to the filament spine. On average, for all halo masses, halo spins become more perpendicular to the filament spine at later times. At all redshifts, the spin alignment shows a considerable variation with filament thickness, with the halo mass corresponding to the transition from parallel to perpendicular alignment varying by more than one order of magnitude. The environmental dependence of halo spin magnitude shows little evolution for $z \leq 2$ and is likely a consequence of the correlations in the initial conditions or high redshift effects

Wang et al. (2020): Galaxies, as well as their satellites, are known to form within the cosmic web, the large, multi-scale distribution of matter in the universe. It is known that the surrounding large-scale structure (LSS) can impact and influence the formation of galaxies, e.g., the spin and shape of halos or galaxies are correlated with the LSS and the correlation depends on halo mass or galaxy morphology. In this work, we use group and filament catalogs constructed from the SDSS DR12 to investigate the correlation between satellite systems and the large-scale filaments they are located in. We find that the distribution of satellites is significantly correlated with filaments, namely the major axis of the satellite systems are preferentially aligned with the spine of the closest filament. Stronger alignment signals are found for the cases where the system is far from the filament spine, while systems close to the filament spine show significantly weaker alignment. Our results suggest that satellites are accreted along filaments, which agrees with previous works. The case where the system is far from the filament spine may help us to understand how the filament forms as well as the peculiar satellite distribution in the local universe.

4.6 Cosmic web: missing baryons

Tuominen et al. (2020): Context. A significant fraction of the predicted baryons remains undetected in the local universe. We adopted the common assumption that a large fraction of the missing baryons corresponds to the hot ($\log T(K) = 5.5{-}7$) phase of the Warm Hot Intergalactic Medium (WHIM). We base our missing baryons search on the scenario whereby the WHIM has been heated up via accretion shocks and galactic outflows, and is concentrated towards the filaments of the Cosmic Web. Aims. Our aim is to improve the observational search of the poorly detected hot WHIM. Methods. We detect the filamentary structure within the EAGLE simulation by applying the Bisous formalism to the galaxy distribution. In addition, we use the MMF/NEXUS+ classification of the large scale environment of the dark matter component in EAGLE. We then study the spatio-thermal distribution of the hot baryons within the extracted filaments. Results. While the filaments occupy only 5% of the full simulation volume, the diffuse hot intergalactic medium in filaments amounts to 23% - 25% of the total baryon budget, or 79% - 87% of all the hot WHIM. The most optimal filament sample, with a missing baryon mass fraction of 82%, is obtained by selecting Bisous filaments with a high galaxy luminosity density. For these filaments we derived analytic formulae for the radial gas density and temperature profiles, consistent with recent Planck SZ and CMB lensing observations within the central $r \sim 1$ Mpc. Conclusions. Results from EAGLE suggest that the missing baryons are strongly concentrated towards the filament axes. Since the filament finding methods used here are applicable to galaxy surveys, a large fraction of the missing baryons can be localised by focusing the observational efforts on the central 1 Mpc regions of the filaments. Moreover, focusing on high galaxy luminosity density regions will optimise the observational signal.

Ahoranta et al. (2020): Aims: We explore the high spectral resolution X-ray data towards the quasar 3C 273 to search for signals of hot ($\sim 10^6 - 10^7 K$) X-ray-absorbing gas co-located with two established intergalactic far-ultraviolet (FUV) O VI absorbers. Methods: We analyze the soft X-ray band grating data of all XMM-Newton and Chandra instruments to search for the hot phase absorption lines at the FUV predicted redshifts. The viability of potential line detections is examined by adopting the constraints of a physically justified absorption model. The WHIM hypothesis is investigated with a complementary 3D galaxy distribution analysis and by detailed comparison of the measurement results to the WHIM properties in the EAGLE cosmological, hydrodynamical simulation. Results: At one of the examined FUV redshifts, $z = 0.09017 \pm 0.00003$, we measured signals of two hot ion species, O VIII and Ne IX, with a 3.9σ combined significance level. While the absorption signal is only marginally detected in individual co-added spectra, considering the line features in all instruments collectively and assuming collisional equilibrium for absorbing gas, we were able to constrain the temperature ($kT = 0.26 \pm 0.03$ keV) and the column density ($NH \times Z_{\odot}/Z = 1.3 - 0.5 + 0.6 \times 10^{19}$ cm^{-2}) of the absorber. Thermal analysis indicates that FUV and X-ray absorption relate to different phases, with estimated temperatures, TFUV $\approx 3 \times 10^5$, and, TX - ray $\approx 3 \times 10^6$ K. These temperatures match the EAGLE predictions for WHIM at the FUV/X-ray measured

Nion-ranges. We detected a large scale galactic filament crossing the sight-line at the redshift of the absorption, linking the absorption to this structure. Conclusions: This study provides observational insights into co-existing warm and hot gas within a WHIM filament and estimates the ratio of the hot and warm phases. Because the hot phase is thermally distinct from the O VI gas, the estimated baryon content of the absorber is increased, conveying the promise of X-ray follow-up studies of FUV detected WHIM in refining the picture of the missing baryons.

4.7 Structure and evolution of galaxies

Kipper et al. (2020a): A galaxy moving through a background of dark matter particles induces an overdensity of these particles or a wake behind it. The back reaction of this wake on the galaxy is a force field that can be decomposed into an effective deceleration (called dynamical friction) and a tidal field. In this paper, we determine the tidal forces, thus generated on the galaxy, and the resulting observables, which are shown to be warps, lopsidedness, and/or kinematic-photometric position angle misalignments. We estimate the magnitude of the tidal-like effects needed to reproduce the observed warp and lopsidedness on the isolated galaxy IC 2487. Within a realistic range of dark matter distribution properties, the observed, warped, and lopsided kinematical properties of IC 2487 are possible to reproduce (the background medium of dark matter particles has a velocity dispersion of ≤ 80 km/s and the density $10^4 - 10^5 M_{\odot} kpc^{-3}$, more likely at the lower end). We conclude that the proposed mechanism can generate warps, lopsidedness, and misalignments observed in isolated galaxies or galaxies in loose groups. The method can be used also to constrain dark matter spatial and velocity distribution properties.

Izzo et al. (2020): We observed the optical afterglow of GRB 201026A (Cenko et al., GCN 28784) using the Nordic Optical Telescope (NOT) equipped with the ALFOSC imaging camera. A set of 2x300 s and 5x200 s images was secured in the SDSS r and z bands, respectively. The mid time of the observation was Oct 26.968 (36.2 min after the GRB). Observations were conducted at high airmass under moderate seeing conditions (1.4”). No new object is detected consistent with the XRT position, down to a limiting magnitude $r = 21.5$, $z = 21.4$ AB (3 sigma), calibrated against nearby stars from the Pan-STARRS catalog. We note the presence of a faint, possibly extended object visible in the archival Pan-STARRS images, at a position consistent (RA = 13:06:58.71, Dec = +83:46:58.5) with that of the X-ray afterglow. This object could be the host galaxy of GRB 201026A, but we caution that the currently available uncertainty radius of the XRT position is still relatively large (3.9”), hence the association not robust.

4.8 Structure of the Galaxy and Local Group

Libeskind et al. (2020): We present the HESTIA simulation suite: High-resolutions Environmental Simulations of The Immediate Area, a set of cosmological simulations of the Local Group. Initial conditions constrained by the observed peculiar velocity of nearby galaxies are employed to accurately simulate the local cosmography. Halo pairs that resemble the Local Group are found in low resolutions constrained, dark matter only simulations, and selected for higher resolution magneto hydrodynamic simulation using the AREPO code. Baryonic physics follows the AURIGA model of galaxy formation. The simulations contain a high-resolution region of 3-5 Mpc in radius from the Local Group mid-point embedded in the correct cosmographic landscape. Within this region, a simulated Local Group consisting of a Milky Way and Andromeda like galaxy forms, whose description is in excellent agreement with observations. The simulated Local Group galaxies resemble the Milky Way and Andromeda in terms of their halo mass, mass ratio, stellar disc mass, morphology separation, relative velocity, rotation curves, bulge-disc morphology, satellite galaxy stellar mass function, satellite radial distribution, and in some cases, the presence of a Magellanic cloud like object. Because these simulations properly model the Local Group in their cosmographic context, they provide a testing ground for questions where environment is thought to play an important role.

Kipper (2020): Galaxy evolution is not determined by a single process, but a multitude of smaller effects. Accretion of gas, accretion of small satellites, major mergers, gas depletion, ram pressure stripping, strangulation, mass quenching are just a few processes that affect the evolution of galaxies. Since the possibilities are numerous and the causes are somewhat degenerated, it is difficult to model all effects consistently. For example, if a population of galaxies has negligible star formation, it is difficult to determine, what is the cause of it. We present a novel stochastic modelling that allows to disentangle different effects by modelling the movement of galaxies in the SFR-Mstar plane. We use the well tested GAMA data for our modelling. In the process of modelling, we rely only on observational data. As one of our preliminary results, we could distinguish major merger event rate and ram pressure stripping event rate to be about 1:10, while self-consistently modelling the rest of studied processes. Results of this analysis will be published in Kipper, Tempel et al. (in prep).

Kipper et al. (2020b): We determine the mass of the Milky Way bar and the torque it causes, using Gaia DR2, by applying the orbital arc method. Based on this, we have found that the gravitational acceleration is not directed towards the centre of our Galaxy but a few degrees away from it. We propose that the tangential acceleration component is caused by the bar of the Galaxy. Calculations based on our model suggest that the torque experienced by the region around the Sun is $\sim 2400\, km^2 s^{-2}$ per solar mass. The mass estimate for the bar is $\sim 1.6 \pm 0.3 \times 10^{10} M_{\odot}$. Using greatly improved data from Gaia DR2, we have computed the acceleration field to great accuracy by adapting the orbital Probability Density Function (oPDF) method (Han et al. 2016) locally and used the phase space coordinates of $\sim 4 \times 10^5$ stars within a distance of 0.5 kpc from the Sun. In the orbital arc method, the first step is to guess an acceleration field and then reconstruct the stellar orbits using this acceleration for all the stars within a specified region. Next, the stars are redistributed along orbits to check if the overall phase space distribution has changed. We repeat this process until we find an acceleration field that results in a new phase space distribution that is the same as the one that we started with; we have then recovered the true underlying acceleration.

Kipper & Tempel (2020): Since past few decades, observations have improved so strongly that when modelling Milky Way (MW) dynamics it is required to include small perturbations to the modelling process. It is difficult task that we try to solve by selecting regions to model so small that the perturbation can be considered to give nearly constant effect. We use Solar Neighbourhood (SN) as our test sample and assume that the bar effects show more or less constant contribution to SN. By extrapolating and smoothing observed stars on their orbits, and requiring that smoothed and observed phase space are consistent we were able to deduce acceleration vector. We conclude from non-radial acceleration component that the bar must cause about one third of total acceleration near SN.

Kalberla et al. (2020a): Context. There are significant amounts of H2 in the Milky Way. Due to its symmetry H2 does not radiate at radio frequencies. CO is thought to be a tracer for H2; however, CO is formed at significantly higher opacities than H2. Thus, toward high Galactic latitudes significant amounts of H2 are hidden and are called CO-dark. Aims: We demonstrate that the dust-to-gas ratio is a tool for identifying locations and column densities of CO-dark H2. Methods: We adopt the hypothesis of a constant E(B-V)/NH ratio, independent of phase transitions from H I to H2. We investigate the Doppler temperatures TD, from a Gaussian decomposition of HI4PI data, to study temperature dependences of E(B-V)/NHI. Results: The E(B-V)/NHI ratio in the cold H I gas phase is high in comparison to the warmer phase. We consider this as evidence that cold H I gas toward high Galactic latitudes is associated with H2. Beyond CO-bright regions, for TD ≤ 1165 K we find a correlation (NHI + 2NH2)/NHI $\sim -\log TD$. In combination with a factor $XCO = 4.0 \times 10^{20} cm^{-2}$ (K km/s) this yields NH/E(B-V) ~ 5.1 to $6.7 \times 10^{21} cm^{-2} mag^{-1}$ for the full sky, which is compatible with X-ray scattering and UV absorption line observations. Conclusions: Cold H I with $TD \leq 1165$ K contains on average 46% CO-dark H_2. Prominent filaments have $T_D \leq 220$ K and typical excitation temperatures Tex ~ 50 K. With a molecular gas fraction of $\leq 61\%$ they are dominated dynamically by H2.

Kalberla & Haud (2020); Kalberla et al. (2020b): Context. The interstellar medium is affected by turbulence and observed H i structures in channel maps are shaped by turbulent motions. It is taken for granted by a few theoreticians that observed H i structures do not represent real density enhancement but velocity caustics, caused by velocity crowding. This interpretation was questioned and objections by Clark et al. led to violent debates. Aims. To settle the discussion we verify theoretical key parameters by using Effelsberg Bonn H i Survey (EBHIS) observations. Methods. We apply unsharp masking to determine filamentary H i structures at high spatial frequencies. In addition we use Gaussian parameters to distinguish the cold neutral medium (CNM) from observed H i column densities. We compare power spectra and spatial distributions of dust and H i column densities, distinguishing CNM and multiphase column densities at various velocity widths. Results. Observations contradict the Velocity Channel Analysis (VCA) postulate that the spectral index should steepen with the width of the velocity window. We rather find that the thin slice spectral index depends strongly on the H i phase composition. Multiphase power spectra are steeper for regions with cold gas. VCA denies such H i phase dependencies on the power distribution. Separating the CNM we find that the power spectra are significantly flatter than those for the multiphase H i composite. We observe excess CNM power for small scale structures originating from cold dust bearing filaments that are embedded in the CNM. Spectral indices for narrow channel widths depend on the Doppler temperature of the H i gas. In presence of enhanced small scale H i structure the far infrared emission from dust is also enhanced. Conclusions. Small scale cold filamentary H i structures are predominantly caused by density enhancements due to phase transitions rather than by velocity caustics.

4.9 High-energy astrophysics

Aydi et al. (2020): Classical novae are thermonuclear explosions that occur on the surfaces of white dwarf stars in interacting binary systems. It has long been thought that the luminosity of classical novae is powered by continued nuclear burning on the surface of the white dwarf after the initial runaway. However, recent observations of gigaelectronvolt γ-rays from classical novae have hinted that shocks internal to the nova ejecta may dominate the nova emission. Shocks have also been suggested to power the luminosity of events as diverse as stellar mergers, supernovae and tidal disruption events, but observational confirmation has been lacking. Here we report simultaneous space-based optical and γ-ray observations of the 2018 nova V906 Carinae (ASASSN-18fv), revealing a remarkable series of distinct correlated flares in both bands. The optical and γ-ray flares occur simultaneously, implying a common origin in shocks. During the flares, the nova luminosity doubles, implying that the bulk of the luminosity is shock powered. Furthermore, we detect concurrent but weak X-ray emission from deeply embedded shocks, confirming that the shock power does not appear in the X-ray band and supporting its emergence at longer wavelengths. Our data, spanning the spectrum from radio to γ-ray, provide direct evidence that shocks can power substantial luminosity in classical novae and other optical transients.

Fang et al. (2020): Shock interaction has been argued to play a role in powering a range of optical transients, including supernovae, classical novae, stellar mergers, tidal disruption events, and fast blue optical transients. These same shocks can accelerate relativistic ions, generating high-energy neutrino and gamma-ray emission via hadronic pion production. The recent discovery of time-correlated optical and gamma-ray emission in classical novae has revealed the important role of radiative shocks in powering these events, enabling an unprecedented view of the properties of ion acceleration, including its efficiency and energy spectrum, under similar physical conditions to shocks in extragalactic transients. Here we introduce a model for connecting the radiated optical fluence of nonrelativistic transients to their maximal neutrino and gamma-ray fluence. We apply this technique to a wide range of extragalactic transient classes in order to place limits on their contributions to the cosmological high-energy gamma-ray and neutrino backgrounds. Based on a simple model for diffusive shock acceleration at radiative shocks, calibrated to novae, we demonstrate that several of the most luminous transients can accelerate protons up to 10^{16} eV, sufficient to contribute to the IceCube astrophysical background. Furthermore, several of the considered sources—particularly hydrogen-poor supernovae—may serve as "gamma-ray-hidden" neutrino sources owing to the high gamma-ray opacity of their ejecta, evading constraints imposed by the nonblazar Fermi Large Area Telescope background. However, adopting an ion acceleration efficiency of $\sim 0.3\% \sim 1\%$ motivated by nova observations, we find that currently known classes of nonrelativistic, potentially shock-powered transients contribute at most a few percent of the total IceCube background.

Sokolovsky et al. (2020a): Shocks in γ-ray emitting classical novae are expected to produce bright thermal and non-thermal X-rays. We test this prediction with simultaneous NuSTAR and Fermi/LAT observations of nova V906 Car, which exhibited the brightest GeV γ-ray emission to date. The nova is detected in hard X-rays while it is still γ-ray bright, but contrary to simple theoretical expectations, the detected $3.5 - 78$ keV emission of V906 Car is much weaker than the simultaneously observed ¿100 MeV emission. No non-thermal X-ray emission is detected, and our deep limits imply that the γ-rays are likely hadronic. After correcting for substantial absorption (NH $= 2 \times 10^{23}$ cm^{-2}), the thermal X-ray luminosity (from a 9 keV optically thin plasma) is just ~ 2 per cent of the γ-ray luminosity. We consider possible explanations for the low thermal X-ray luminosity, including the X-rays being suppressed by corrugated, radiative shock fronts or the X-rays from the γ-ray producing shock are hidden behind an even larger absorbing column (NH $> 10^{25}$ cm^{-2}. Adding XMM-Newton and Swift/XRT observations to our analysis, we find that the evolution of the intrinsic X-ray absorption requires the nova shell to be expelled 24 d after the outburst onset. The X-ray spectra show that the ejecta are enhanced in nitrogen and oxygen, and the nova occurred on the surface of a CO-type white dwarf. We see no indication of a distinct supersoft phase in the X-ray light curve, which, after considering the absorption effects, may point to a low mass of the white dwarf hosting the nova.

Sokolovsky et al. (2020b): The classical nova explosion in the previously known cataclysmic variable MGAB-V207 was reported by R. H. McNaught on 2020-07-15.590 UT (CBET 4811). Pre-discovery all-sky camera images by M. A. Phillips show the nova peaking on 2020-07-11.76 at 3.7mag (CBET 4812).

Ribeiro et al. (2020): Superluminous Supernovae (SLSNe) are a rare class of supernova with luminosity 100-1000 times greater than standard supernovae. Different emission models have been proposed for both Type I (hydrogen poor) and Type II (hydrogen rich) SLSNe to explain the strong optical output, such as powering by a central engine or interactions with circumstellar material. High energy gamma-rays may escape from a central engine through an expanding ejecta at late times (10s - 100s days), providing a possible signal to explore both the ejecta and central engine. This project searched for high-energy gamma-ray emission (600 MeV to 500 GeV and 200 GeV to 10TeV) from two SLSNe by analyzing data from Fermi-LAT and VERITAS observatories. Both SN2015bn and SN2017egm are Type I SLSNe, which are predicted to be powered by a central compact object, and are bright, worthwhile candidates to search for this late-time emission. No gamma-ray emission was detected from either source in these energy ranges, but upper limits on flux and luminosity were derived.

5 List of collaborators

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