Cosmic Flows 2025: Probing the Universe with Peculiar Velocities

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Book of Abstracts

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Cosmic Flows : from datasets to cosmology

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We use direct galaxy distances to compute the 3D peculiar/gravitational velocity field, enabling us to reconstruct the mass distribution driving these motions. Filaments, walls, and voids are integrated into a broader view of large-scale gravitational structures defined by empty regions. The key benefit of mapping superclusters as watershed basins is their robust definition, making them reliable cosmological probes. We will present the latest dynamic map with five newly charted supercluster-watersheds neighboring Laniakea. Additionally, we will discuss measurements related to the cosmological principle of homogeneity and gravitational law : bulk flow, fσ8 and H0. We will discuss the analysis of new datasets such as FAST-DR1, WALLABY Pilot data, DESI-PV-DR1, and the future 4HS.

Session 12 / 2

Probing the missing baryons with the kinetic Sunyaev-Zeldovich effect

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The kinetic Sunyaev-Zeldovich (kSZ) effect represents a secondary anisotropy in the cosmic microwave background (CMB) radiation, caused by the inverse Compton scattering of free electrons in galaxy clusters. Observations from the Planck satellite, as well as the ACT and SPT experiments, have enabled the measurement of this effect, providing insights into the dynamics of large-scale structures. In this talk, I will review recent advancements in the study of the kSZ effect using data from Planck, ACT, and SPT. I will demonstrate how cross-correlation of the kSZ effect with the peculiar velocity field and pairwise momentum field helps trace the distribution of missing baryons. Additionally, I will explore its physical relationship with the thermal Sunyaev-Zeldovich (tSZ) effect.

Session 2 / 3

DESI Peculiar Velocity Survey - Year 1 Fundamental Plane

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In this talk I will present the some of the peculiar velocity measurements from the first year of observations from the Dark Energy Spectroscopic Instrument (DESI) which will be used alongside redshift space distortion measurements to constrain the growth rate of structure. Over five years DESI is using a 5000 fibre spectrograph to map 3D positions of tens of millions of galaxies. At the same time we are using the "Fundamental Plane" technique to measure peculiar velocities for about 375,000 early-type galaxies. This sample will be the largest peculiar velocity sample to date, dwarfing the state-of-the-art SDSS catalogue of ~30,000 peculiar velocities. I will describe the data collection and analysis pipelines, as well as presenting our peculiar velocity measurements for ~100,000 galaxies

in Data Release 1, including analysis of the robustness of our results to selection criteria and our choices for correction parameters.

Session 13 / 4

Measuring the growth rate from the SDSSv survey using auto- and cross- power spectrum of the galaxy density and momentum fields

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The large-scale structure of the Universe and its evolution over time contains an abundance of cosmological information.One way to unlock this is by measuring the density and momentum power spectrum from the positions and peculiar velocities of galaxies, and fitting the cosmological parameters from these power spectrum.In this work, we will explore the cross power spectrum between the density and momentum fields of galaxies. We derive the estimator of the density-momentum cross power spectrum multipoles. The growth rate of the large-scale-structure, $f\sigma_8$ is measured from fitting the combined density monopole, momentum monopole and cross dipole power spectrum. The estimators and models of power spectrum as well as our fitting method have been tested using mock catalogues, and we find that they perform well in recovering the fiducial values of the cosmological parameters of the simulations, and we also find that the errors of the parameters can be largely reduced by including the cross-power spectrum in the fit. We measure the auto-density, auto-momentum and cross power spectrum using the Sloan Digital Sky Survey Data Release 14 peculiar velocity catalogue. The fit result of the growth rate $f\sigma_8$ is $f\sigma_8 = 0.413^{+0.050}_{-0.058}$ at effective redshift $z_{\rm eff} = 0.073$, and our measurement is consistent with the prediction of the Λ Cold Dark Matter cosmological model assuming General Relativity.

Session 13 / 5

The Cosmic Dipole Problem

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I will present our recent results exploring the integrity of the cosmological principle, the idea that, on sufficient scales, the universe is homogeneous and isotropic. Recent tensions have arisen between the dipole of cosmological sources and its interpretation from the CMB as a kinematic departure from the local Hubble Flow, bringing the cosmological principle into doubt. With a Bayesian-based approach, I explore the cosmological dipole in several cosmological surveys, using Bayesian evidence to assess differing hypotheses. The conclusion is that the picture is not completely clear, and the question of the cosmological principle remains to be answered.

Session 9 / 6

Preparing for WAVES: Evaluating Galaxy Group-Finders with Shark v2 Mock Catalogues

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The Wide Area Vista Extragalactic Survey (WAVES) is part of a suite of ambitious surveys utilizing the dedicated 4-meter Multi-Object Spectrograph (4MOST) in Chile. WAVES aims to measure the redshifts of 1.7 million galaxies and is scheduled to launch in December 2025. These next-generation redshift surveys are essential for probing the large-scale structure of the universe, offering unparalleled insight into the distribution of galaxies, clusters, and filaments. Identifying and analyzing these structures in a consistent and robust way is crucial for fully leveraging the data these surveys will produce.

A key method for studying large-scale structure is through galaxy group identification using group-finding algorithms, such as the widely used friends-of-friends and halo-based methods. However, the variety of group finders now available—each tailored to different surveys—raises questions about their comparative performance. In this talk, I present a systematic comparison of the most well-known group-finding algorithms by running them on realistic mock catalogues built using the Shark v2 semi-analytical model. Additionally, I discuss the work of the WAVES structure-finding technical working group and highlight the data products that will be made available to the scientific community.

The identification of galaxy groups is closely tied to the study of peculiar velocities, as these velocities are influenced by the gravitational potential of large-scale structures. By identifying galaxy groups, WAVES will contribute valuable information to the broader study of peculiar velocities, enabling the refinement of cosmic flow models and enhancing our understanding of the dark matter distribution in the local universe.

Session 8 / 7

Investigating the obscured core of the Vela Supercluster with MeerKAT

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The Vela supercluster (VSCL) is an extended and massive supercluster located at l ˜ 275°±15°; |b| < 10°, and cz ˜ 18000 km s-1. Its location is of particular interest in view of its proximity to the apex, where residual bulk flows suggest a considerable surplus of mass. However, a major fraction of its extent has little data below Galactic latitudes of |b| < 7–8° because of the obscuration by the Milky Way Plane.
The long wavelength from HI emission is the only tool that allows us to systematically probe this obscured region. We leverage the greatly enhanced sensitivity and angular resolution of the SKA precursor, MeerKAT, to map gas-rich galaxies within the inner structure of VSCL, out to cz ˜ 25500 km s-1 (z ˜ 0.085). This encompasses two complementary HI surveys at 260° < l < 290°, -2° < b < 1°; and 263° < l < 284°, |b| < 6.7°, sensitive to normal spiral galaxies at the VSCL distance over ˜300 deg2. More than 1500 heavily obscured galaxies were discovered within the Vela volume, most of which

were newly identified. Roughly 800 were located within the deepest extinction layers, and ˜700 were situated above and below the Galactic Plane. We found indications of the core that revealed two overdense, wall-like structures that align with the walls identified at higher latitudes by Kraan-Korteweg et al. (2017). They also are consistent with predictions from recent independent velocity field reconstructions. With adequate photometry, the data quality and statistics are sufficient to potentially determine peculiar velocities.

Session 1 / 8

Optimising 4MOST survey strategy for peculiar velocity surveys

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4MOST is a next-generation survey that will start operating in 2025 and will carry out a five-year survey program. 4MOST consists of 18 individual surveys that will be operationally carried out as a single survey. Among those 18 surveys, there are specific peculiar velocity subsurveys that will significantly extend currently available catalogues of peculiar velocities. To optimise the 4MOST survey strategy for peculiar velocity surveys requires special attention to maximise the scientific benefit. For example, 4MOST will follow up supernovae detected by the LSST, which requires that LSST and 4MOST survey strategies are aligned. In the 4MOST survey optimisation this is taken into account in the 4MOST long-term scheduler algorithm.

In the current talk, I will give a brief overview of the 4MOST survey optimisation. I will more specifically describe how 4MOST survey strategy is optimised for the peculiar velocity surveys.

References:
1) Tempel et al. 2020, MNRAS, "An optimized tiling pattern for multiobject spectroscopic surveys: application to the 4MOST survey"
2) Tempel et al. 2020, A&A, "Probabilistic fibre-to-target assignment algorithm for multi-object spectroscopic surveys"
3) Tempel et al. in prep, "Long-term scheduler algorithm for the 4MOST survey"

Session 4 / 9

Cosmicflows-4 Cosmography

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The Cosmography inferred for the Cosmicflows-4 Catalog of 56000 peculiar velocities is presented, expanding on the HMC reconstruction recently published in Valade et al, Nature Astronomy (2024). Beside the 3D mapping of the overdensity and velocity fields, a map of the V-Web is constructed by analysis of the eigenvalues of the shear tensor. Earlier findings in the structure of the Cosmic V-Web, such as the Cen-Pup-PP filament or the South Pole Wall, obtained with Cosmicflows-2 and Cosmicflows-3, are confirmed. A particular attention is given to the mapping of structures located within or crossing the zone of galactic obscuration, as well as the structures located in the previously uncharted regions now covered in Cosmicflows-4 thanks to the inclusion of the SDSS-PV sample, out to 30000 km/s in the galactic north, including the basin of attraction of the Sloan Great Wall and that of the Hercules Supercluster.

Session 12 / 10

Analyzing the Large-Scale Bulk Flow using CosmicFlows4: Tension with the Standard Cosmological model

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We present estimates of the Bulk Flow in volumes of increasing radii using the minimum variance method with data from the CosmicFlows4 catalog. Contrary to expectations, we find that the Bulk Flow amplitude increases with increasing radius, with the Bulk Flow amplitude in a volume of radius $200h^{-1}$Mpc being large enough to have only a 0.003% chance of occurring in the Standard Model. We discuss the detailed characteristics of the Large-Scale Bulk Flow with an eye to better understand its origin.

Session 13 / 11

Understanding the role of peculiar velocities in void cosmology

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Cosmic voids, large under-dense regions in the Universe, serve as promising laboratories for extracting cosmological information. They offer opportunities to explore deviations from ΛCDM and provide insights into dark energy and modification of gravity. Upcoming surveys will enable detailed void analyses, allowing access to a huge number of voids. Voids' significance lies in their spherically symmetric property when stacked, becoming standard spheres. However, observationally, they exhibit two types of distortions crucial for extracting cosmological information: redshift-space distortions (RSD), caused by galaxy peculiar velocities, and geometrical distortions, arising from the use of incorrect cosmological models when converting observed redshifts into distances (Alcock-Paczynski test). Modeling RSD requires the challenging task of accounting for peculiar velocities, and current models have proven insufficient for accurately describing smaller voids. This limitation can be addressed by reconstructing the velocity field. In this work, I present improvements in performing the Alcock-Paczynski test on voids after applying a Zeldovich reconstruction to model RSD. This approach allows for the inclusion of smaller voids in the analysis and significantly enhances the precision of cosmological parameter constraints.

Session 5 / 12

The Velocity Field Olympics: Assessing velocity field reconstructions with direct distance tracers

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The peculiar velocity field of the local Universe provides direct insights into its matter distribution and the underlying theory of gravity, and is essential in cosmological analyses for distinguishing systematic deviations from the Hubble flow. Numerous methods have been developed to reconstruct the local density and velocity fields (at z

$lesssim 0.05$), typically constrained by redshift-space galaxy positions (e.g., 2M++) or by direct distance tracers such as the Tully-Fisher relation, the fundamental plane, and supernovae (e.g., CosmicFlows). We introduce a comprehensive validation framework to evaluate the accuracy of these reconstructions against catalogues of direct distance tracers and examine their relative ability to explain the peculiar velocities of objects within these catalogues. Our framework assesses the goodness-of-fit of each reconstruction using Bayesian evidence, residual redshift discrepancies, velocity scaling, and the need for external bulk flows. Applying this framework to a suite of reconstructions—including those derived from the Bayesian Origin Reconstruction from Galaxies (BORG) algorithm and from linear theory—we find that non-linear BORG reconstructions consistently outperform others. However, the efficacy of these comparisons is strongly influenced by the resolution at which the reconstructions are constrained, and our conclusions are based only on "average" goodness-of-fit of the reconstructions, rather than the velocities of individual objects or specific regions.

Session 4 / 13

Identification of basins of attraction in the local Universe & more

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Scarce, anisotropic, extremely noisy and prone to various biases: peculiar velocity surveys are not trivial to interpret. In this talk, I'll present HAMLET, a powerful GPU-oriented code that implements a field-level forward modeling method, which enables the reconstruction of the matter distribution in the Local Universe and the large scale motion associated to it. An application to the 38,000 (groups of) galaxies of the Cosmicflows-4 catalog will be discussed, notably the mapping of Basins of Attractions with a full probabilistic approach, as well as the constraining of $f\sigma_8$ from ZTF-like SNIe data. Finally, the non-linear improvements to the method and the use of HAMLET for the constraining of initial conditions for cosmological simulations will be presented.

Session 9 / 14

SNe Ia intrinsic scatter systematic in $f\sigma_8$ measurements

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Type Ia supernovae have been widely used to constrain the dark energy density and its equation of state parameter. The statistics and homogeneity expected from new generations of photometric surveys such as ZTF and Rubin-LSST will allow us to use SNe Ia to probe large-scale structures and make new constraints on parameters including the growth rate of structure, $f\sigma_8$. To prepare for these analyses, we need to identify and study the impact of SNe Ia systematics on the measurement of $f\sigma_8$. In the recent DES analysis, the intrinsic scatter model of SNe Ia was found to be the main systematic in the dark energy equation-of-state parameter. In this talk, I present my current work to explore the impact of this systematic on $f\sigma_8$ using simulations of Rubin-LSST.

Session 2 / 15

Improving SN Ia Hubble residual scatter with galaxy groups

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Various cosmological parameters such as H_0 and $f\sigma_8$ that can be measured using Type Ia Supernovae (SNe Ia) have been shown to be in tension with measurements from the early universe. We can improve cosmological parameter measurements and reduce scatter on the Hubble diagram by focusing on redshift scatter from leveraging galaxies in groups. Using the low-redshift sample from Pantheon+ combined with a new sample from the AAT spectrograph as well as predictions from simulations with Uchuu, we obtain and average the redshifts of galaxy groups to correct for small-scale peculiar velocities and improve scatter on the Hubble diagram. With the impending arrival of the Rubin-LSST data, which we show will greatly benefit from accounting for peculiar velocities, we encourage an increased effort to define more galaxy groups for both current and future SN samples.

Session 12 / 16

The TRGB-SBF Project: a Pop II path to H0

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The path from Cepheid variables to type Ia supernovae gives a value of the Hubble constant which significantly disagrees with the value determined from observations of conditions in the early universe and a cosmological model. A totally independent measurement of H0 from observed redshifts and distances is needed to evaluate the possibilities of systematic errors. A path is being explored that should be as accurate or better than the Cepheid-SNIa way, involving only observations of old evolve stars. Gaia parallaxes ground the absolute vales of RR Lyrae stars that establish the absolute magnitudes of stars at the tip of the red giant branch that set the scale of the power spectrum of surface brightness fluctuations in E/S0 galaxies that are observed at redshifts with negligible confusion from peculiar velocities. Observations with JWST are fundamental for the success of this program.

Session 10 / 17

Testing gravity with DESI and supernovae correlations

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Correlations between new large-scale structure and transient surveys allow us to perform novel tests of gravitational physics. Peculiar velocities create magnitude fluctuations in transient sources. In this talk I will present correlation measurements using data from the Dark Energy Spectroscopic Instrument and Pantheon+ supernovae magnitudes along with matched simulations. By fitting cosmological models to the results we perform measurements of the local growth rate of structure. We compare these measurements to the predictions of the standard cosmological model and present forecasts for future surveys.

Session 13 / 18

Measuring the growth rate of structure from the Pantheon+ supernova sample

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At low redshift, peculiar velocities are particularly well-suited to studying the nature of dark energy through the growth rate of structure. Supernovae Ia are precise distance indicators, and we can estimate peculiar velocities from their Hubble residuals at low-redshift, i.e., roughly their departure from motion caused purely by expansion. The Pantheon+ supernova sample is currently the most expansive low-redshift all-sky supernova sample. Pantheon+ corrected for peculiar velocities in their analysis, so we remove the corrections to use them as peculiar velocity tracers. As a proof-of-concept for what is to come from next-generation all-sky, homogeneous supernova Ia surveys, we measure $f\sigma_8$ from the Pantheon+ supernovae alone for the first time.

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Tracing the Local Void and its substructures with MeerKAT

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Voids are extended low density regions. Recent studies have shown that they have substructure consisting of sub-voids, walls, tendrils, filaments and nodes. Moreover, the structure formation in voids appears to be similar to structure formation of a low density universe. Numerical simulations suggest that the galaxies in voids may preferentially lie within these filamentary void substructures. It is therefore interesting to explore whether the intricate substructure expected from hierarchical structure formation process can be traced observationally.

The Local Void is the nearest large void. Nevertheless its properties are extremely difficult to observe it since a major part of the void is located behind the Galactic bulge. In this presentation, we will present a detailed study of the Local Void and its surroundings in the ZOA using the MeerKAT Galactic Plane Survey to search for the HI-emission of Local Void galaxies within Galactic longitude and latitudes of 330 deg < l < 55 deg and |b| < 1.5 deg, out to redshifts of z < 7500 km/s. We find that the extent of the Void is ~ 58 Mpc at these low Galactic latitudes. We then classify the detected galaxies based on their environment and we find that the galaxies in the Void tend to have HI masses that are lower compared to average density counterparts. We also identify several small group candidates, both in the Void and at its edge. These groups in the Void show signs of filamentary substructure. We furthermore compare the small-scale clustering of the HI selected galaxies in the Void and average density regions.

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Extracting cosmological information from galaxy peculiar velocities using machine learning

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A powerful approach to constraining cosmological parameters from galaxy peculiar velocities is to train graph neural networks (GNNs) for field-level likelihood-free inference without scale restrictions. We developed models that robustly infer the value of $\Omega_{\rm m}$ using only the positions and radial velocities of galaxies, achieving resilience to various astrophysical complexities, sub-grid models, and galaxy/sub-halo finders. However, real-world observations present significant challenges, such as (i) masking, (ii) uncertainties in peculiar velocities and radial distances, and (iii) diverse galaxy population selections. Additionally, observational data are limited to redshifts, where radial positions and velocities become entangled. In this talk, I will present how we trained and tested these GNN models on synthetic galaxy catalogs from thousands of state-of-the-art hydrodynamic simulations generated by different codes within the CAMELS project, with and without observational effects. Despite the challenges, our results show that over 90% of galaxy catalogs retain high performance and robustness, underscoring the potential of this approach for real-world data applications.

Session 10 / 21

Dipoles and structures in cosmological numerical relativity simulations

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We apply fully general relativistic (GR) ray-tracing to large cosmological simulations. The simulations of Macpherson et al. integrate the full Einstein equations from initial conditions at the cosmic microwave background (CMB) to the present epoch. These simulations reproduce a realistic cosmic web from the initial matter power spectrum, which is already well studied.

For the first time, we study how light from isotropic sources at large distances out to redshift $z = 3$ is affected by intervening structure in GR simulations. An ensemble of simulated observers in the fluid rest frame, at various locations in the cosmic web, all measure a dipole in the observed photon energies. The magnitude of each of these simulated dipoles is comparable to the magnitude of our observed CMB dipole. However, this dipole does not disappear in the simulation rest frame —which should be close to FLRW. Thus it cannot be associated with the observer's peculiar velocity.

The principal contributions to this dipole are from structures at redshifts $z < 0.1$, those nearby each observer contributing the most. When these structures are cut, isotropy is restored.

Session 9 / 22

More precise distances for early-type galaxies using machine learning

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Galaxy distances measured using the Fundamental Plane have relative errors of 20-30%. Beyond a few tens of Mpc, this means that the errors in galaxy peculiar velocities are generally larger than the peculiar velocities themselves. It is therefore highly desirable to find ways to reduce the uncertainties in Fundamental Plane distance estimates. The intrinsic scatter about the Fundamental Plane has been demonstrated to be dominated by mass-to-light ratio variations associated with the age of the stellar population. For individual galaxies, however, the uncertainties in measured ages are so large that attempts to correct for this age dependence increase, rather than decrease, the scatter in the Fundamental Plane. The best that can be done is to limit samples to the oldest galaxies, which reduces the scatter at the cost of reducing the sample size. We have therefore investigated the use of machine learning combined with measurements of a wide range of galaxy properties to obtain more precise distances. Applying a relatively simple convolutional neural network to early-type galaxies in the value-added SDSS catalogue, we are able to reduce the scatter about the Fundamental Plane by a factor of 2. We identify the galaxy properties that are most important to achieving this improvement and suggest possible physical mechanisms leading to the reduced scatter. If this result translates to smaller peculiar velocity errors, and can be extended to other datasets, it will greatly increase the precision and power of the next generation of peculiar velocity surveys.

Session 10 / 23

HI galaxy simulations for SKAO peculiar velocities

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With the advent of next-generation radio observations with the upcoming SKA Observatory, HI Galaxy surveys will be able to probe the late-time Universe with unprecedented sensitivity, offering the possibility to constraint cosmology in a complementary manner to standard spectroscopic surveys. In preparation for this scientific case, realistic simulations of large-sky volumes with good resolution are needed. In this talk I will discuss Semi-analytic models (SAM) that combine the advantages of relatively large box sizes and resolutions fine enough to resolve galaxy substructures. In particular, I will present a study of HI galaxies 21cm lines based on the state-of-the-art Galaxy Evolution and Assembly (GAEA) SAM. We model the characteristic double-peak feature of the 21cm lines and obtain predictions for the HI Tully Fisher relation. We validate the simulation by constructing mock light cones for comparing to real observations and exploring systematic effects. We further predict the redshift distribution of HI galaxies, in particular of HI galaxies for which the TF signal is detectable, depending on survey specifications. These type of study are key for understanding the realistic constraining power of HI galaxy redshift surveys with the SKAO, and in particular of peculiar velocity surveys.

Session 5 / 24

Large-scale motions, growth rate, and the Hubble constant from the Tully-Fisher relation

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A density field mapped from a galaxy redshift survey can be used to predict the peculiar velocity field, up to normalisation and any external tidal field. Fitting such a model for the predicted peculiar velocities to those measured using a distance estimator such as the Tully-Fisher relation provides a test for theories of gravity via a measurement of the growth factor. We present a Bayesian forward-modelling method that simultaneously determines the parameters of both the Tully-Fisher relation and the peculiar velocity field, while incorporating a selection function and an intrinsic Tully-Fisher scatter model. We also show how this methodology can be applied to improve upon Tully-Fisher measurements of the Hubble constant and directly measure possible variations of H_0 on the sky. The former is currently limited by uncertainties in the absolute calibration, but the latter is only limited by sample size and sky/redshift coverage. These methods were applied to the Cosmiclfows-4 Tully-Fisher dataset to obtain measurements on the growth rate, H_0, and a possible dipole in H_0. Using Tully-Fisher mocks of the ongoing WALLABY survey, we show the extent to which each of these constraints will be improved.

Session 2 / 25

WALLABY: a southern Tully-Fisher survey

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We report on the successful completion and release of HI data for 2,400 galaxies from the ASKAP WALLABY pilot surveys covering 300 sq.deg of (mainly) southern sky. We also provide an update on the 5-yr full WALLABY survey which is mapping galaxies in HI over a further 15,000 sq.deg. It is anticipated that, by 2028, WALLABY will have 200,000 redshifts and velocity widths for the purposes of distance determination and cosmological studies, including flow fields, Hubble constant, and growth rates. Combined with optical/radio data from northern surveys (e.g. FAST and DESI) and new methods of velocity width determination, we will shortly enter a new era of precision local cosmology.

Session 7 / 26

Peculiar velocities and peculiar expansion: the timescape perspective

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The timescape model revisits the foundations of general relativity —the issues of quasilocal energy and angular momentum in a universe with large complex structures. Quantitative predictions had to wait til the 2020s for observations to reach a precision to distinguish the timescape model from the 100-year old Friedmann-Lemaître models, on which standard cosmology is based. With a huge variety of new data now pouring in, standard cosmology is increasingly challenged. But the timescape is fitting well [1], and offering new insights into simulations [2], new questions, and potentially a change to our fundamental paradigm.

Inhomogeneous exact solutions of Einstein's equations for cosmological relativity generally exhibit peculiar expansion distinguishable from peculiar motion on a FLRW background. The timescape is built on a quasilocal uniform Hubble expansion condition, which seeks a foundational basis for framing these distinctions. It leads to predictions now supported by very strong ($\ln B \sim 5$) Bayesian evidence [1]. The next phase will need collaboration with the observational peculiar velocity community. In this talk, I will present an overview aimed at fostering such joint exploration.

References

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Session 14 / 27

Probing cosmology with the peculiar velocity field

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Peculiar velocities are velocities imparted onto galaxies by the gravitational influence of their local environment, and so are uniquely suited to be optimal probes of cosmic growth in the local universe. Current and future surveys will cover the entire sky out to redshift z ˜ 0.15 and will measure peculiar velocities for hundreds of thousands of galaxies in that volume. Using such an abundance of data, we will be able to measure the growth rate of large-scale structure with accuracy comparable to the sub-one percent measurements of the cosmic expansion history. In this presentation, I will describe my work in utilising direct peculiar velocity measurements and the peculiar velocity field to measure cosmological parameters. In particular, I will discuss how galaxy clustering and peculiar velocities statistics may be commbined to produce more accurate constraints of the growth rate, and how reconstructions of the local peculiar velocity field inferred from the galaxy density field may be used to reduce the error on estimates of the Hubble constant made with standard sirens and standard candles.

Session 7 / 28

Cosmic rainstorms

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There is an analogy between terrestrial and cosmic watersheds, and river networks. A terrestrial (usual) watershed is a patch of land where water all flows into the same river. Cosmic watersheds gather matter into the cosmic web of walls and filaments, all flowing inward toward galaxies. How good is that analogy? One quantitative way to investigate this question is through a "cosmic rainstorm," in which cosmic expansion is halted briefly, hastening matter raining down onto the cosmic web. I will discuss the results of simulation experiments of cosmic rainstorms, and discuss some related issues.

Session 12 / 29

Cosmic Flow Challenges

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Cosmic flows are currently undergoing a renaissance with major new peculiar velocity and redshift surveys such as 4HS, DESI and ZTF, as well as new methods like kinetic Sunyaev-Zeldovich effect at high redshifts. I will review the challenges of current data sets that must be overcome to turn Cosmic Flows into competitive cosmological probe, and prospects for the future.

Session 8 / 30

The Hubble flow model around the Local Group

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We analyzed the velocity field near the Local Group outside the virial zones of Milky Way and Andromeda galaxies on scales from 400 to 1400 kpc. The Hubble flow model allows us to estimate the total mass of the Local Group of $M_{\mathrm{LG}} = (2.42 \pm 0.12) \times 10^{12}\ M_{\odot}$, which is in excellent agreement with the sum of the individual masses of Our Galaxy and Andromeda inside their virial zones $M_{\mathrm{MW+M31}} = (2.49 \pm 0.43) \times 10^{12}\ M_{\odot}$. There is no statistically significant increase of the total mass with distance on a scale from 400 to 1400 kpc. We conclude that essentially the entire mass of the Local Group is clustered within 300-400 kpc around our Galaxy ant the Andromeda Galaxy.

Session 8 / 31

Newly mapped large-scale structures along the SARAO MeerKAT Galactic Plane Survey

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The deep SARAO MeerKAT Galactic Plane Survey (SMGPS) covers the whole southern Milky Way along a narrow strip of Δ⊠ ~ 3◦. While primarily aimed at exploring the inner Galaxy, the SMGPS provides a unique opportunity to trace the large-scale distribution of galaxies from their redshifted HI-line emission. Thanks to the excellent resolution and sensitivity of the SMGPS (rms = 0.30-0.60 mJy/beam), the HI-survey is sensitive to 9.6 x 10ˆ9M⊠ galaxies throughout the probed volume of cz < 25,000 km/s, encompassing the full distance range relevant to bulk flow, and at the GA distance to galaxies of 10ˆ8M⊠.
To date, 2300 HI-galaxies were detected along longitude range 55◦ < l < 260◦, of which only 119 were previously identified in HIZOA. I will present results on the Local Void, its extent and population,

the continuation of the OphSCL across the ZOA, the surprising prominence of the GA-Wall in the inner Zone of Avoidance, as well as a newly uncovered structure in close proximity to the GA. New insights into the Vela SCL will presented by S. Rajohnson.

Session 8 / **32**

Cosmography of the Local Volume

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A representative sample of nearby galaxies is the basis for solving various problems of extragalactic astronomy, a source of important information about galaxies, their formation and evolution, distribution in space and the formation of the large-scale structure of the Universe. The Local Volume, a sphere of about 10 Mpc radius, gives us a unique opportunity to observe a large number of dwarf galaxies of extremely low surface brightness, inaccessible to observations at large distances. We will present the current status and ongoing projects to study Local Volume galaxies, search for new galaxies, calibrate distance scales, and map their distribution in space.

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How much information can be extracted from galaxy data at the field level?

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Field-level inference (FLI) of 3D galaxy data such as those from galaxy surveys or peculiar velocity surveys guarantee optimal constraints since there is no data compression (hence information loss). FLI is further tied to a forward model; such forward model also allows for flexible, modular treatment of differen astrophysical and observational effects, including but not limited to galaxy bias and redshift-space distortion. In this talk, I will present the first unbiased constraints on growth of structure with FLI from simulated data of galaxy clustering. I will further discuss ongoing developements to extend FLI to include other observables such as galaxy peculiar velocity and intrinsic shapes.

Reference: arXiv:2403.03220

Session 5 / **34**

Reconstructing the density and velocity fields using a V-Net

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The standard model of cosmology, LambdaCDM, predicts a velocity field generated by, and coupled to, the distribution of matter density perturbations. This coupling, β, can be directly predicted from the theory of gravity, and when it is measured, can be used to test the cosmological model. However, correctly modelling the predicted velocity field, beyond linear theory, can be challenging. Machine learning offers the possibility of a complete representation from incomplete data, and can be used to reconstruct the underlying density and velocity fields from the discrete tracer galaxies. We use a convolutional neural network, a V-net, trained on numerical simulations of structure formation to reconstruct the density and velocity fields. We find that, with detailed tuning of the loss function, the V-net could produce better fits to the density field in the high-density and low-density regions, and improved predictions for the probability distribution of the amplitudes of the velocities. However, the weights also reduce the precision of the estimated β parameter. We estimate the velocity field β parameter by comparing the peculiar velocities of halo catalogues to the reconstructed velocity fields, and find the estimated β values agree with the fiducial value at the 68\% confidence level.

Session 2 / 35

The Dark Energy Bedrock All-Sky Supernova Survey

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Type Ia supernova science holds steady as one of the leading probes to study the behavior of our universe, and yet, even the most complete and advanced datasets to date suffer from poor statistics and systematics at low redshift. To combat these pitfalls, the Dark Energy Bedrock All-Sky Supernovae (DEBASS) program will provide the largest consistently calibrated low-z SN Ia data in the southern hemisphere, helping improve measures of bulk flow and universe isotropy. At this time, DEBASS has accumulated more than 350 spectroscopically confirmed SN Ia within the redshift range out to z˜0.08 using the Dark Energy Camera for 3.5 nights per semester over the last 4 years. In this talk, we will introduce the DEBASS program, discuss its science goals and the advantages it presents to supernova cosmology, and introduce the upcoming DEBASS early data release, composed of 56 SNe located within the Dark Energy Survey footprint.

Session 2 / 37

DESI Peculiar Velocity Survey: Fundamental Plane

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The Dark Energy Spectroscopic Instrument (DESI) Peculiar Velocity Survey aims to measure the peculiar velocities of early- and late-type galaxies within the DESI footprint using both the Fundamental Plane and Tully-Fisher relations. These direct measurements promise to tighten constraints on the growth rate by a factor of 2.5 at z=0.1 compared to redshift-space distortions alone. I'll present our method for assessing stellar velocity dispersions from DESI spectra and establishing the Fundamental Plane. After calibrating our sample using SBF, we constructed the Hubble diagram and estimated a Hubble constant of H0 = 76.05 ± 0.35 (statistical) ± 0.49 (systematic FP) ± 4.86 (statistical

due to calibration) km sˆ-1 Mpcˆ-1. I'll discuss key systematics and their impacts and look ahead to upcoming DESI releases and future surveys like WALLABY and 4HS.

Session 5 / **38**

Delving Beyond the Missing Pages in the Story of the Universe with the help of Peculiar Velocities

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Over the last two decades, the rapid increase in both quantity and quality of cosmological observations has revealed growing evidence of discrepancies between values of key cosmological parameters within the standard model when measured using late vs early universe probes. Gravitational wave observations could provide new insight into these "cosmological tensions" by enabling independent measurements of contested parameters, such as the present-day expansion rate of the universe (H0). However, to do this, we require accurate measurements of gravitational wave signals, our observations of which are distorted by the local matter distribution during their propagation to Earth.

My research focuses on creating a map of galaxy motions in the local universe to determine matter density distribution and recover undistorted gravitational wave signals, enabling unbiased measurements of parameters like H0. Today, I will present a novel machine learning technique being developed to reconstruct the peculiar velocity field using redshift observations from the Dark Energy Spectroscopic Instrument (DESI). The key aspect of this new reconstruction technique is that is preserves information about galaxy motions on significantly smaller scales than previous methods, enabling more accurate recovery of undistorted gravitational wave signals.

Session 10 / **39**

Maximum likelihood inference of growth rate with SNIa velocity and galaxy density fields

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Using supernovae of type Ia for inferring the growth rate of structure (fσ8) has seen a significant gain in interest in recent years. In particular, maximizing the potential of fσ8 constraints can be achieved by coupling peculiar velocity estimators with the underlying density field. I will present a recent software called flip (Ravoux et al. in prep.(a), https://github.com/corentinravoux/flip), allowing to perform this measurement with a maximum likelihood inference method. The mathematical framework on which flip is based allows the reproduction of all the previous models of field-level covariance for velocities and densities in an algorithmically optimized way with Hankel transforms. Furthermore, the flip software contains improvements such as the simultaneous inference of all nuisance parameters (including velocity estimators), accounting for redshift dependence, and extending field-level covariance models. An earlier software version was used to prove the feasibility of measuring fσ8 on ZTF simulations (Carreres et al. 2023). Currently, flip is being tested to measure fσ8 with Pantheon+ data, in LSST simulations (Rosselli et al. in prep., Carrerres et al. in prep.), and on simulations coupling ZTF SNIa with DESI galaxy field (Ravoux et al.(b) in prep.). I will give a general presentation of the flip software, its core concepts, and the results associated with the previously mentioned studies.

Session 12 / 40

Evaluating bulk flow estimators for CosmicFlows-4 measurements

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For over a decade there have been contradictory claims in the literature regarding measurements of local bulk flow motions of galaxies, as to whether measurements are consistent or in tension with the currently accepted model of cosmology, Lambda-CDM. A bulk flow measurement can be thought of as an average of galaxy motions sourced by gravity in a volume of space. The robustness of various popular bulk flow estimators have not previously been investigated. In this talk I will discuss the research I have done to investigate the accuracy and precision of a few bulk flow estimators with simulations. I also present a bulk flow measurement using the largest catalogue of peculiar velocities to date, which is consistent with the direction of previous bulk flow measurements but has a larger amplitude than predicted by Lambda-CDM. The bulk flow indicates a strong pull in the negative super-galactic 'x'which lies out of sight, behind the plane of the Milky Way.

Session 1 / 41

Welcome

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Session 7 / 42

What is a Peculiar Velocity?

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In this talk I will look at some theoretical details of peculiar velocities. We'll explore different ways that peculiar velocities can be measured and corrected for. We'll discuss what it means to say "space is expanding"and answer the question of whether it is possible to have a galaxy "at rest"with respect to us if it is beyond the Hubble sphere (which is similar to asking whether a ruler can extend beyond the Hubble sphere). Finally, we may also explore whether the movement in our local Universe warps our view of the Universe beyond.

Session 1 / 43

A High-Statistics Tully-Fisher Catalog using Fiber Spectroscopy

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The Tully-Fisher relation (TFR) is an empirical correlation between the instrinsic luminosity of a spiral galaxy and its asymptotic rotational velocity. Here we present measurements of the TFR from a secondary target program at the Dark Energy Spectroscopic Instrument, a robotic fiber-fed spectrograph located at Kitt Peak National Observatory. By positioning fibers on the galaxies' nuclei and their semimajor axes at a distance of 0.4R_26, where R_26 is the 26th-magnitude/arcsecˆ2 r-band isophote, we can remove the galaxies' systemic velocities and infer their rotational velocities. Since the DESI main survey began in May 2021, we have collected more than 30,000 TFR measurements of nearby spiral galaxies. In this talk, we describe the TFR secondary target program, the data reduction, and compare the inferred TFR to other measurement techniques using emission line widths.

Session 13 / 44

Investigating beyond ΛCDM using the state-of-art supernova sample from the Dark Energy Survey

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Type Ia Supernovae act as standard candles which provide a fundamental way to probe the expansion history of the Universe. While the standard cosmological model fits current data well, uncertainty remains. This uncertainty has led to a wealth of exotic cosmological models being proposed. In my work, I constrain a variety non-standard models using the DES 5-year sample - the largest single sample of SNe Ia to date. In this talk, I will present these results. I will also discuss cosmological assumptions that appear in the main DES supernova cosmology analyses, evaluate their impact, and provide guidance on when the DES Hubble diagram can be used to test non-standard models.

Session 5 / 45

Impacts of Peculiar Velocities on Standard Siren Cosmology

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As we discover increasing numbers of gravitational wave sources, our ability to use them for Cosmological studies advances. With next-generation gravitational-wave observatories, we expect constraints on H0 using gravitational waves to reach the sub-percent level. We must first understand the systematic uncertainties that affect current gravitational-wave cosmological methods to achieve this. This work focuses on quantifying the errors in H0 estimates that arise when neglecting peculiar velocity corrections with Standard Sirens. We find that disregarding peculiar velocity corrections leads to biases and increased uncertainties in H0 on the order of ˜4%.

Session 4 / 47

Peculiar Velocity Reconstruction from Simulations and Observations Using Deep Learning Algorithms

Author: Yuyu Wang[None]

In this paper, we introduce a U-Net model of deep learning algorithms for reconstructions of the 3D peculiar velocity field, which simplifies the reconstruction process with enhanced precision. We test the adaptability of the U-Net model with simulation data under more realistic conditions, including the redshift space distortion effect and halo mass threshold. Our results show that the U-Net model outperforms the analytical method that runs under ideal conditions, with a 16% improvement in precision, 13% in residuals, 18% in correlation coefficient, and 27% in average coherence. The deep learning algorithm exhibits exceptional capacities to capture velocity features in nonlinear regions and substantially improve reconstruction precision in boundary regions. We then apply the U-Net model trained under Sloan Digital Sky Survey (SDSS) observational conditions to the SDSS Data Release 7 data for observational 3D peculiar velocity reconstructions.

Session 9 / 48

Cosmology with peculiar velocities and machine learning

Author: Francisco Villaescusa-Navarro[None]

I will present a new framework to infer the value of cosmological parameters from peculiar velocity surveys. Our approach, which has been tested on thousands of state-of-the-art cosmological hydrodynamic simulations from the CAMELS project, takes a set of galaxies, together with their peculiar velocities, and performs field-level simulation-based inference while marginalizing over baryonic effects. We show that including peculiar velocities is key to extracting robust cosmological information.

Session 9 / 49

CLONES: Digital Twins of the Local Universe based on peculiar velocities

Author: Jenny Sorce[None]

To understand dark matter and dark energy, which make up 95% of the Universe, cosmological surveys must achieve percent-level precision. However, this precision uncovers tensions between observations and the standard cosmological model, potentially arising from systematic biases. CLONES (Constrained LOcal & Nesting Environment Simulations) are digital twins of the local Universe, derived from the peculiar velocities of galaxies, to faithfully replicate our cosmic environment and address these challenges. This presentation will introduce these CLONES and highlight their capabilities through a selection of applications.

Session 1 / 54

Mapping Mass and Motion in the Local Universe with 4HS

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I will give a brief overview of the 4MOST Hemisphere Survey (4HS), with particular emphasis on our cosmology science goals of mapping mass and motion on ˜Gpc scales, and highlighting several key aspects of the 4HS experimental design relative to past and current surveys.

Session 1 / 55

DESI, an overview, peculiar velocities and synergies with ZTF

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In this talk I will give an overview of the Dark Energy Spectroscopic Instrument (DESI) and their first cosmological results from the first-year dataset. I will briefly introduce the DESI peculiar velocity program, aiming the measurement of 180k distances with Tully-Fisher and Fundamental Plane relations. I will also briefly introduce the Zwicky Transient Facility (ZTF) and their supernovae program, which probes the same volume as DESI galaxies and have the potential to yield interesting growth rate measurements from their peculiar velocities, in a joint DESI-ZTF analysis.

Session 3 / 56

Discussion Session: PV surveys

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Session 4 / 58

From Initial Conditions to Peculiar Velocities: A Bayesian Field-Level Approach to the Nearby Universe

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The study of peculiar velocities provides a unique window into the dynamics of the nearby universe, allowing us to probe the non-linear regime of cosmic structure formation and test fundamental physics related to the Universe's expansion. As observational data quality and scale improve, modeling the nearby universe becomes more complex, requiring techniques that capture the non-linear dynamics and specificities of the matter and velocity distributions around us.

In this talk, I will present a physics-informed field-level inference framework that bridges early and late-time cosmology by reconstructing both density and velocity fields from observational data. Through Bayesian physical forward modeling, we jointly infer initial conditions and map non-linear density and velocity fields, providing dynamic structure formation histories of the nearby universe with rigorous uncertainty quantification.

I will highlight recent advances using the 2M++ galaxy compilation to reconstruct the universe's initial conditions and non-linear gravitational evolution. Our approach reproduces ΛCDM statistics, such as the power spectrum, bispectrum, and halo mass function, while resolving the detailed three-dimensional galaxy distribution, including precise mass estimates for individual galaxy clusters.

Additionally, I will present comparisons of our inferred velocity fields with state-of-the-art results, demonstrating consistent improvements in velocity inference. Finally, I will discuss extensions of our method to model highly non-linear systems, such as the Milky Way–Andromeda pair, leading to deeper insights into complex cosmic structure dynamics.

These advancements open new avenues for using peculiar velocities and galaxy clustering data to explore cosmic structure formation and the dynamic interplay of matter and gravity in the universe.

Session 6 / 59

Local Universe with Cosmicflows-4

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The large-scale structures in our local Universe emerge from the rivalry between gravitation and the expansion of the Universe, akin to a cosmic tug-of-war. Peculiar velocities of galaxies reflect their motion primarily governed by gravitational interactions, making them unbiased dynamical tracers of the total matter in the Universe (including dark and luminous matter). These velocities serve as crucial tools for testing the LCDM cosmological model. The Cosmicflows collaboration prepares catalogs of galaxy distances, enabling the derivation of radial peculiar velocities of galaxies. In this talk, I will demonstrate how deep learning techniques can reconstruct the local dark matter density and three-dimensional peculiar velocity fields from line-of-sight galaxy peculiar velocities.

Session 6 / 60

Discussion Session: Reconstructions

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Session 7 / 61

The Hitchhiker's Guide to the Galaxy (peculiar velocities)

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Peculiar velocities surveys are going to play a key role in testing our knowledge about the nearby universe and our cosmological assumptions. In this talk, I will review what peculiar velocities are and some recent fundings and analysis that I have been developed concerning these novel observables. In particular, I will focus on the information we can extrapolate about peculiar velocities from datasets as Pantheon+SH0ES.

Session 11 / 62

Assessing the Accuracy of Density-Velocity Comparison Methods on Cosmological Parameters

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A promising method for measuring $f\sigma 8$ involves comparing observed peculiar velocities with those predicted from a galaxy density field using linear perturbation theory. While previous studies have evaluated the effectiveness of this method using N-body simulations these typically focus on idealized mock galaxy surveys which ignore systematic biases that can arise solely due to survey selection effects. Using mock catalogues that replicate the 2M++ density field, we explore the impact of these various effects individually and collectively in order to quantify the accuracy and precision of this method. We find the reconstruction and analysis methods used for our 2M++ mocks produce a value

of $f\sigma_8$ that is biased high, and calibrating recent peculiar velocity samples we find a linear $f\sigma_8$= 0.362 ± 0.023. Building on these findings, we explore how reconstructing cosmological redshifts using peculiar velocities influence measurements of the Hubble constant (H0). Recent measurements of H0 using type Ia supernovae explicitly correct for their estimated peculiar velocities using the 2M++ reconstruction of the local density field. However, the amount of uncertainty that is generated due to this reconstruction has thus far been unquantified. To rectify this we use our mock 2M++ catalogues and their predicted peculiar velocities, to quantify this component of the error budget.

Session 11 / 63

Discussion Session: The role of ML and simulations

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Session 14 / 64

Discussion Session: Cosmology

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Session 7 / 65

The Metric of the Local Universe

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Does the Universe look the same everywhere? Are we living in a special place?
These questions have intrigued laypeople and philosophers alike for centuries, but for the first time, astronomers are in the position of addressing them quantitatively. Existing state-of-the-art maps of the Universe around us, combined with an upcoming wealth of observational data, compel us to seek a deeper understanding of our cosmic neighbourhood, its origin and its future. In this talk, I will review the latest theoretical efforts in the quest for "the metric of the local Universe" and demonstrate how cosmic flows in our cosmic environment offer perhaps the best tools to unveil the intricate geometry of our local spacetime.

Session 10 / 66

Constraining matter-radiation equality with peculiar velocity

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The latest Dark Energy Spectroscopic Instrument (DESI) survey results show that dark energy could evolve with time. This is achieved by constraining one of the standard rulers: the sound horizon at the drag epoch, with DESI Baryon Acoustic Oscillation, Cosmic Microwave Background, and supernovae. However, we could also constrain cosmological parameters with the other standard ruler: the particle horizon during the matter-radiation equality. In this talk, I will explain how to constrain the scale of matter-radiation equality with peculiar velocity. I have developed a model-independent

method to constrain the scale of matter-radiation equality with the galaxy and velocity power spectra. Our method improves the constraint on the scale of radiation-radiation equality by around 50% compared to the previous method that only uses the galaxy power spectrum. In the future, we can apply this method to the DESI survey to constrain the scale of matter-radiation equality at different redshift bins. Combining this with other datasets can constrain cosmological parameters and potentially provide a complementary test for the time evolution of dark energy.