Joseph Ivor Silk

Professor of Physics at the Institut d'Astrophysique, Université Pierre et Marie Curie, Paris; Homewood Professor in the Department of Physics and Astronomy, Johns Hopkins University, Baltimore; Senior Fellow in the Beecroft Institute of Particle Astrophysics and Cosmology, Department of Physics, University of Oxford

2011 Balzan Prize for the Early Universe (From the Planck Time to the First Galaxies)

For his pioneering work on the early evolution of the Universe, studying the effects of various physical processes and phenomena such as dark matter and space curvature on the fluctuations of the Cosmic Microwave Background and the formation of galaxies of different types.

Institution Administering Research Funds: New College, University of Oxford

Adviser for the Balzan General Prize Committee: Bengt Gustafsson

An Oxford New College - Johns Hopkins Centre for Cosmological Studies

Cosmology is in a golden age of discovery, but a deeper understanding of what is meant by a science of cosmology, in the fuller reaches of these words, is in its infancy. It must involve astrophysics, physics, philosophy, and cosmogony, and tackle genuinely fundamental questions in cosmology.

Joseph Silk has designated part of his Balzan research funds for the creation of a Centre for Cosmological Studies based at New College Oxford and at the Department of Physics and Astronomy at the Johns Hopkins University in Baltimore. It will also involve the Oxford University Department of Physics and the Institut d'Astrophysique of the Université Pierre et Marie Curie in Paris.

The Centre's goal will be to provide Balzan grants for young researchers in cosmology in frontier areas of research that are consistent with the scientific themes supported by the Centre, and to establish international links involving leading young researchers to develop scientific interactions and collaborations that will benefit their careers as well as enhance the scientific life of the partner institution. The first grants were awarded in the autumn of 2013 to Visiting Junior Research Fellows who will be hosted at the three institutions mentioned above.

Projects: Balzan Awardees 2013/14

Sarah Andreas (DESY Theory Group, Hamburg, Germany): visit to Johns Hopkins University, October 2013

Hidden Sectors with Hidden Photons and Dark Matter

Hidden sectors are frequently proposed as part of the physics beyond the standard model. This research is concerned with the phenomenology of models with a hidden sector which possesses an extra U(1) symmetry, is connected to the standard model through the corresponding light U(1) gauge boson and possibly contains a candidate for dark matter. Experimental constraints were derived on the mass $m_{\gamma'}$ and interaction strength χ of this new light gauge boson, the hidden photon γ', and further examine the possibilities to search for this particle in future experiments. After having studied the dark matter particle of these hidden sector models with respect to its signature in direct detection experiments (e.g., LUX), Dr. Andreas continued to analyse the corresponding constraints from different indirect searches. Such models in which dark matter interacts via a light mediator like the hidden photon are additionally of interest since this self-interacting dark matter might undergo gravothermal collapse and allow the formation of massive black holes. In this context, Andreas studies the possibility and consequences of energy losses due to the *Bremsstrahlung* of hidden photons.

Shant Baghram (Institute for Research in Fundamental Sciences, Iran): visit to Institut d'Astrophysique, September 2013

Effects of structures (galaxies and voids) in expansion rate measurement of SNIa (In preparation)

The accelerated expansion of the Universe and the physical mechanism behind it is one of the main open questions in cosmology, known as the Dark Energy problem. The standard model of (Lambda) CDM can explain the observational data, like luminosity distance of Supernova type Ia (SNIa) and the CMB power spectrum. However, there are other alternatives for cosmological constants, like the effect of structures on the expansion rate of the universe, modified gravity theories and dark energy models.

In this research project, the effect of large scale structures like cosmic voids and galaxies (group of galaxies) on the luminosity distance of SNIa-s will be investigated. This effect can be quantified by the total amount of gravitational lensing convergence κ_g and Doppler lensing effect parameters κ_v ($\kappa = \kappa_g + \kappa_d$). Using the SDSS DR10 void catalogue, the lensing convergence function for each line of sight of SNIa was produced. The deviation of distance modulus ($\Delta\mu = \mu - \mu^m$) from the standard model and its correlation with the lensing convergence parameter was investigated. Results show that the current catalogue of large scale structures SDSS DR10 up to redshift z=0.15 with the Union2 catalogue (considering the observational uncertainties) shows no significant deviation from the standard model.

Jonathan Davis (Institute for Particle Physics Phenomenology, Durham University): visit to Johns Hopkins University, October 2013

Dr. Davis primarily worked with Professor Joseph Silk on a novel signal of Dark Matter particles in both our own galaxy and others, the basic idea being that particles of Dark Matter annihilate with themselves near sites of shock acceleration. This results in the products of such annihilations, such as electrons or protons, being injected into these shocks, which would then potentially accelerate such particles to high energies. These particles could then be detected on Earth as cosmic rays.

It was shown that the signal of these cosmic rays could be distinguished from the background under certain conditions. The work is soon to be completed and will appear on the arXiv shortly.

Yohan Dubois (Institut d'Astrophysique de Paris): visit to Astrophysics, University of Oxford, November 2013

Dr Dubois' recent research has focused on two different topics:

1) The evolution of mass and spin of supermassive black holes (BH).

2) The alignment of galaxies with the cosmic web.

By means of high-resolution hydrodynamical simulations, Dubois and his colleagues from Oxford and Paris have shown that BHs at the heart of galaxies are spun up by gas accretion from the dense gas in galaxies. Due to the strong time coherence of the gas accretion onto the BH, the accreted gas angular momentum adds up constructively to the BH angular momentum (Dubois et al., 2014a). Those compact objects keep very large values (close to maximum) until a galaxy merger and binary BH-BH coalescence re-orientate the direction of the spin and change its magnitude (Dubois et al., 2014b).

The large-scale hydro cosmological simulation, Horizon-AGN (PI Y. Dubois, co-I J. Devriendt, C. Pichon), has led to the investigation of how galaxies are aligned with the cosmic filaments. The simulation self-consistently follows the gas dynamics, the star formation process within galaxies and the feedback from stars and from BHs. Therefore, the simulation allows for large variety in simulated galaxies, from dwarf to massive, passive to actively star-forming, blue to red. They have shown that low-mass, blue, star-forming, rotation-supported galaxies tend to align their angular momentum with their cosmic filament, while massive, red, passive and pressure-supported galaxies are more perpendicularly orientated to the filament axis (Dubois et al., 2014c). Galaxy mergers that rapidly swing the spin axis of the galaxy remnant drive the transition from alignment to misalignment (Welker et al., in preparation).

Related publications:

Dubois Y, Volonteri M, Silk J, Devriendt J, Slyz A. 2014. Black hole evolution: II. Spinning black holes in a supernova-driven turbulent interstellar medium. MNRAS (submitted 2014a).

Dubois Y, Volonteri M, Silk J. 2014. Black hole evolution: III. Statistical properties of BH spins using large-scale hydrodynamical cosmological simulations. MNRAS (submitted, 2014b).

Dubois Y, Pichon C, Welker C, Le Borgne D, Devriendt J et al. Dancing in the dark: galactic properties trace spin swings along the cosmic web. MNRAS (submitted, 2014c).

Welker C, Devriendt J, Dubois Y, Peirani S, Pichon C. Mergers drive spin swings along the cosmic web. In preparation.

Ely Kovetz (Department of Physics, Weinberg Theory Group, University of Texas): visit to Johns Hopkins University, June 2013

The ideal method to detect the curl-component, or B-mode, signature of inflationary gravitational waves (IGWs) in the cosmic microwave background (CMB) polarization, in the absence of foregrounds and lensing, is a prolonged integration over a single patch of sky of a few square degrees. However, since foregrounds abound, the sensitivity to B modes can be improved considerably by finding the region of sky cleanest of foregrounds. The best strategy to detect B modes thus involves a trade-off between exploration (to find lower-foreground patches) and exploitation (through prolonged integration). The question is how to balance this trade-off efficiently. This problem has similar properties to the multi-armed bandit (MAB) problem in probability theory, wherein a gambler faces a series of slot machines with unknown winning odds and must develop a strategy to maximize his/her winnings with some finite number of pulls. While the optimal MAB strategy remains to be determined, a number of algorithms have been developed in an effort to maximize the winnings.

In order to develop adaptive survey strategies to optimize the sensitivity to IGW B modes, the search for IGW B modes was formulated in the presence of spatially-varying foregrounds as an MAB problem and demonstrated, using realistic foreground models and taking lensing-induced B modes into account, that adaptive experiments can substantially improve the upper bound on the tensor-to-scalar ratio (by factors of 2–3 in single frequency experiments, and possibly even more). Similar techniques can be applied to other surveys, including 21-cm measurements of signatures of the epoch of reionization, searches for a stochastic primordial gravitational wave background, deep-field imaging by the James Webb Space Telescope or various radio interferometers, and transient follow-up searches. A few of these other implementations are now being investigated in follow-up work.

A preprint of this work has recently been uploaded to the arXiv (http://arxiv.org/pdf/1308.1404.pdf) and submitted it to Phys. Rev. D. for review.

Mark Richardson (School of Earth & Space Exploration, Arizona State University): visit to Astrophysics, University of Oxford, October 2013

The cosmological hydrodynamics code Ramses, which uses adaptive mesh refinement was central to this project. Using Ramses and the smoothed-particle hydrodynamics code Hydra, high resolution simulations of energetic feedback from active galactic nuclei (AGN) in a cluster environment were performed. This permitted the comparison of the effect of numerical method (grid vs particle), resolution and feedback model on the impact of this feedback on the environment. Preliminary work involved comparing the impact of feedback on the central cluster gas density by a redshift of 4. The model with AGN feedback (labeled AGN) was compared with that of no AGN feedback (labeled FID). This work is still ongoing, with a publication expected in the spring. Results were to be presented at a this work at a conference in February 2014.

Aditya Rotti (Inter University Center for Astronomy & Astrophysics, India): visit to Johns Hopkins University, July 2013

Measuring our local motion using high precision CMB measurements

The CMB photons can be used to define a global rest frame. Any observer who does not detect a dipole in the CMB temperature anisotropy map can be defined to be at rest - the CMB rest frame. As a result of this motion, the CMB photons arriving from the direction of motion of the observer get Doppler boosted to higher energies while the ones arriving from the direction opposite to the direction of motion are de-boosted to lower energies. In addition to this, the motion of the observer also results in the CMB photons arriving from a slightly different direction, as compared to their direction of arrival had they been observed from the CMB rest frame. These effects result in a distortion of the observed CMB sky.

Specifically, this distortion causes the CMB sky to be rendered statistically anisotropic. The BipoSH basis forms a convenient basis to study the CMB two point correlation function in an anisotropic universe. The coefficients of expansion in this basis, BipoSH coefficients, are a natural generalisation to the well-known CMB angular power spectrum. These BipoSH coefficients completely encode complete information of the distortions induced in a Doppler boosted CMB sky. It can be shown that by measuring the BipoSH coefficients from a Doppler boosted CMB map, it is possible to recover the amplitude and direction of the velocity of the observer. An algorithm was developed to recover the direction and magnitude of the moving observer (with respect to the CMB rest frame) from measurements of Doppler boosted CMB temperature anisotropies.

Researchers:

Project Director: Dr. Chris Lintott

Advisory Committee: Dr. Adrienne Slyz
Professor Marc Kamionkowski
Professor John March-Russell

Balzan Awardees 2013/14

Sarah Andreas
Shant Baghram
Jonathan Davis

Yohan Dubois
Ely Kovetz
Mark Richardson
Aditya Rotti

Link:
http://balzan.new.ox.ac.uk/home.shtml