

## Executive Summary of the programme 'Exploring the energy ladder of the Universe'

During the two weeks from 30 May until 10 June 2016, the workshop gathered 30 scientists from all over the world aiming at discussing topics in Physics of the early Universe related to the possibility to set new energy scales beyond the established traditional ones, basically the recombination and the BBN scales. A special attention was devoted to proposals and ideas able to provide unified solutions to the cosmological puzzles, a realisation of Inflation, a consistent picture of Dark Matter and a model of Baryogenesis, and possibly also to address (phenomenological or purely theoretical) problems in the SM such as neutrino masses and mixing, LHC anomalies (e.g. the 750 GeV diphoton excess), naturalness and hierarchy problems, grandunification, extensions of General Relativity.

The quite broad variety of topics could have been in principle too dispersive with the risk of a lack of interactions among the participants. However, due to the quality of the participants and to the natural links among the topics, it became soon clear, and it is well witnessed by the survey and by the further scientific feedback that we collected and that we present integrally in a separate document, that this actually represents a natural and well blended mix of intrinsically inter-connected topics. In fact a unified discussion, rather than a too focussed and narrow one on a specific topic, presented many different advantages giving the opportunity to all participants to enrich their spectrum, triggering discussions and new collaborations.

The topics have been discussed within a top-down approach, from higher to lower scales, though with some deviations dictated by speakers constraints. Here is a chronological list of the discussed topics:

- First Week
  - \* Grand-unified models and their cosmological applications (speakers: George Leontaris, Borut Bajc, Sofiane Boucenna),
  - \* Inflation 1 (speakers: Mar Bastero-Gil, Carlos Tamarit, Stefan Antusch)
  - \* Baryogenesis (speakers: Laura Covi, Hooman Davoudiasl)

- \* Leptogenesis  
(speakers: Bhupal Dev, Zurab Tavartkiladze)
- Second Week
  - \* Inflation 2  
(speakers: Anupam Mazumdar, Koushik Dutta, Guillermo Balles-teros, Apostolos Pilaftsis),
  - \* Vacuum Instability  
(speaker: Fedor Bezrukov)
  - \* Dark Matter  
(speakers: Rouzbeh Allahverdi, Seng Pei Liew, Alex Merle, Kevork Abazajian, Nobuchika Okada, Debasish Borah, Ayuki Kamada)
  - \* Neutrino Physics  
(speakers: Danny Marfatia, Zhi-zhong Xing, Shun Zhou)

Every afternoon at the end of the talks, the chairmen led discussions on the topics of the talks. Discussions have lasted up to two hours, on average about 1 hour, involving at least at the beginning all participants while specialists on the topic were usually remaining until the end. These discussions have triggered then in the next days various interactions among participants as also clearly emerging from the feedback we received from them. On Wednesday 8th of June, the afternoon discussion has been replaced by a mini-workshop on ‘Dark Matter: beyond the WIMP paradigm’ chaired by Rouzbeh Allahverdi who initially proposed the mini-workshop (from this point of view participant have been also encouraged to be involved in the organization to some level). Four external speakers covered quite a broad and timely variety of DM scenarios that have been intensively investigated during the last years: keV sterile neutrino DM (Marco Drewes), a gravitational origin of DM (Angnis Schmidt-May), decaying DM detectable at IceCube (Stefano Morisi) and composite DM (Masaki Asano).

It is impossible in this summary to report on all topics and issues that have been discussed and what kind of results have been obtained, it would be probably necessarily literally a book of proceedings to give an account of the richness of the physical problems discussed in the workshop. We will try anyway to highlight the main ones with some quotations extracted from the feedback we collected from the speakers (see also the separate file containing

the complete messages we received).

On Inflation it has been clearly stated in many talks and in the discussions that current constraints set by the Planck collaborations in the plane  $r$ - $n_S$  and that seem to exclude simple and important models, such as those with convex potential  $\lambda\phi^n$  with  $n \geq 1$ , should be regarded as quite simplistic, since many different effects can strongly relax these constraints (for example radiative corrections, or for example as stressed in the talk by Mar Baster-Gil by quite reasonable dissipative effects). Other talks have interestingly highlighted the important role of the interplay of more fields for realistic models (e.g. talk by S. Antusch) and the potential role played by the Higgs itself (e.g. talk by C. Tamarit on Higgs portal coupling).

On Baryogenesis most of the talks have focussed on low energy scale models testable in different ways with colliders, including low scale leptogenesis. In this case it is clear that we have entered with the LHC a particularly exciting era where we can test many of these models and for instance the 750 GeV anomalous diphoton excess might play some role (a nice example model presented by Hooman Davoudiasl in his talk). At the end of this stage we might either single out a particular model or otherwise in the absence of any new physics at the TeV scale then high energy models, first of all traditional thermal leptogenesis, will likely be favoured.

In DM a rich variety of models has been discussed. Many talks discussed the opportunities of having a Warm DM such as a sterile neutrino and how this could help understanding some apparent glitches in the standard Cold DM scenario for Large Scale Structure (e.g. the ‘too big to fail problem’ as nicely discussed by Kev Abazajian) or the detected 3.5 KeV line in the X-ray spectrum. In the talk by L. Covi it was also discussed a possible testable WIMP SUSY model also able to explain the Baryon asymmetry (a asymmetric DM model). Other models that might emerge beyond the WIMP paradigm are for example a decaying DM testable with high energy neutrinos at IceCube (talk by S. Morisi in the mini-workshop). Extensions of GR also might lead to alternative models of DM (see talk by Angnis Schmidt-May).

Many talks also discussed the importance of the new opportunity offered by the discovery of Gravitational Waves to test different models of Inflation or Phase Transitions (talks by Urjit Yajnik, Kousish Dutta, Guillermo Ballesteros).

We should conclude saying that from the feedback we received three main interesting positive aspects of the workshop have emerged: i) First of all participants were greatly enthusiastic of the format and the atmosphere strongly encouraged discussions and collaborations (for example N. Okada, Bhupal DeV and many others explicitly mention that they started collaborating with other participants on 2-3 projects). ii) Second many participants have highlighted in their feedback how they could really learn a lot from this workshop from the talks and from discussions, both at an informative level but also at a deeper one, especially of course in fields contiguous to their traditional one, in a way that their participation triggered new research activities. iii) Third we would like to mention that we managed in the end to have 3 female speakers. We would have clearly liked to have a higher number but for this field this can be still regarded as a success (note: the fraction of invited female speakers was  $\sim 30\%$  but somehow female speakers decline rate is much higher).

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