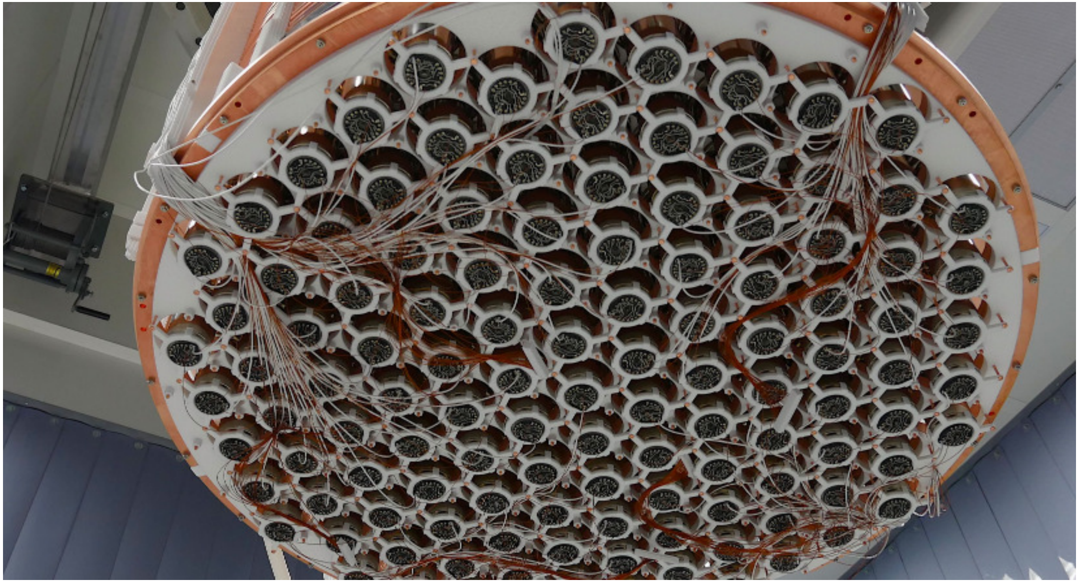
Cosmology, Astro- and Astroparticle Physics



Astrophysics and General Relativity

Prof. Philippe Jetzer, Prof. Prasenjit Saha

35

LIGO (Laser Interferometer Gravitational-Wave Observatory) consists of two Earth-bounded instruments together with Virgo aimed to detect gravitational waves in the frequency range from about 10 to 1000 Hz. In 2015 the first gravitational wave signal has been detected. Since then many more events have been found. Our group has made important contributions to the analysis of LIGO/Virgo data and also in the modelling of more accurate gravitational waveforms. The latter results will be used in LIGO/Virgo and for the future LISA mission and the Einstein Telescope project.

https://www.physik.uzh.ch/g/jetzer

Highlights

The work of the group is focused on the topic of gravitational waves using LIGO/Virgo and the future space mission LISA. In the following we briefly describe some results published in 2020, besides all the works appeared in the framework of the LIGO/Virgo and LISA Pathfinder collaborations.

M. Haney, S. Tiwari and collaborators studied the performance of different search algorithms used in the LIGO/Virgo scientific collaboration to detect eccentric binary black holes. Indeed, several models for the formation of binary black holes predict that most of them are formed with a non-negligible eccentricity. This is an important issue which has to be investigated further also in view of LISA.

In a paper, including as co-authors S. Tiwari, M. Haney and P. Jetzer, a scenario for the merger of black holes in accretion discs of active galactic nuclei has been studied. The expected merging rate for such a scenario has been compared with the observed ones and turned out to be in good agreement. M. Ebersold and S. Tiwari presented in a paper the first results of the search for nonlinear memory effects from subsolar mass binary black hole mergers during the second observing run (O2) of the LIGO and Virgo detectors. No signal was detected as due to the memory effect, and thus this leads

Aerial view of the Virgo interferometer in Cascina, Italy (Image: Virgo/European Gravitational Observatory).

for the first time to an upper limit on the merging rate of very light black holes.

Still another aspect of gravitational waves was investigated by P. Saha and collaborators, who studied the possibility of resolving by optical intensity interferometry a system that LISA is expected to detect in gravitational waves. This could be an exceptional system for which gravitational-wave polarization could be predicted before it is observed.

Philipp Denzel, together with P. Saha and other collaborators, obtained a new estimate of the Hubble constant using gravitational-lensing time delays.

Highlighted Publications:

1. Impact of eccentricity on the gravitational wave searches for binary black holes: High mass case, Phys.Rev. D**102** (2020), 043005, arXiv:2005.14016
2. Binary black hole mergers in AGN accretion discs: gravitational wave rate density estimates, Astron.Astrophys. **638** (2020) A119, arXiv:2005.03571
3. Search for nonlinear memory from subsolar mass compact binary mergers, Phys. Rev. D 101 (2020), 104041, arXiv:2005.03306
4. Towards a polarization prediction for LISA via intensity interferometry, MNRAS **498** (2020) 4577–4589, arXiv:2008.11538
5. The Hubble constant from eight time-delay galaxy lenses, MNRAS **501** (2020), 784–801, arXiv:2007.14398

Astroparticle Physics Experiments

Prof. Laura Baudis

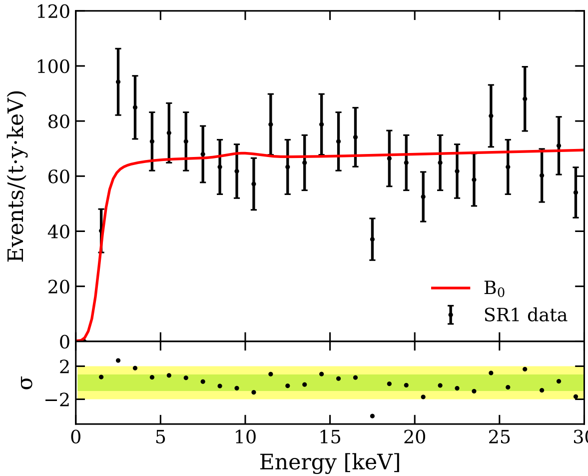
We study the composition of **dark matter** in the Universe and the **fundamental nature of neutrinos**. We build and operate ultra low-background experiments to detect dark matter particles, to search for the neutrinoless double beta decay, a rare nuclear process which only occurs if neutrinos are Majorana particles.
We are members of the **XENON collaboration**, which operates **xenon time projection chambers** to search for rare interactions such as from dark matter, and we lead the **DARWIN collaboration**, with the goal of building a 50 t liquid xenon observatory to address fundamental questions in astroparticle physics.
We are members of the **GERDA** and **LEGEND experiments**, which look for the **neutrinoless double beta decay of ^{76}Ge** in high-purity Ge crystals immersed in liquid argon, with an unprecedented sensitivity.

https://www.physik.uzh.ch/g/baudis

Highlight: Excess events in XENON1T

The XENON1T detector was mainly built to detect interactions of dark matter particles, and has placed the world's most stringent limits on the coherent elastic scattering of weakly interacting massive particles (WIMPs) with xenon nuclei. Due to its exceedingly low background, it is also sensitive to other physics channels and rare events. XENON1T, which was operated underground at Laboratori Nazionali del Gran Sasso, used 3.2 t of ultra-pure liquid xenon, of which 2 t were within the sensitive region of the time projection chamber (TPC): a cylindrical volume that is observed by 248 photomultiplier tubes. The TPC, made out of materials with ultra-low radioactivity levels, allowed for the measurement of the scintillation and ionisation signals induced by a particle interaction. It provided a calorimetric energy measurement, a 3D position reconstruction, and the scatter multiplicity of events.

The data recorded between February 2, 2017 and February 8, 2018, was also analysed to search for solar axions and to look for an enhancement of the neutrino magnetic moment



The XENON1T data (black markers) displaying an excess over the background model, B_0.

from solar neutrinos. If detected, the presence of solar axions would signify a solution to the strong CP problem, hence providing an answer to one of the biggest open questions in particle physics. Also of fundamental importance, an enhancement in the solar neutrino flux could allow to clarify its nature, be it Majorana or Dirac. The analysis also included a search for bosonic dark matter candidates, namely dark photons and axion-like particles.

From an unbinned likelihood fit, the data revealed a surprising excess of events as compared to the expected background model in the low-energy region, as shown in the Figure. The data can be interpreted as a solar axion signal, with a significance of 3.4σ above background, an enhancement in the neutrino magnetic moment favoured at 3.2σ above background, or bosonic dark matter with a mass of 2.3 keV and a local significance of 3.0σ over background. The excess may also be due to a trace amount of tritium in the detector which, if present, would be favoured over background with a significance of 3.2σ. Thus far the XENON collaboration is unable to confirm the nature of the excess, given the available data from the XENON1T experiment; however further clarification is anticipated from the upcoming XENONnT experiment which is currently under commissioning. These results were published and featured in Physical Review D in October 2020 [2]. They have generated great interest in the community, incurring thus far over 200 citations, and have further demonstrated the sensitivity of large xenon TPCs to new physics channels.

Highlighted Publications:

1. Final Results of GERDA on the Search for Neutrinoless Double-BetaDecay,
   GERDA Collab., Phys. Rev. Lett. **125** (2020) 252502
2. Observation of Excess Electronic Recoil Events in XENON1T,
   XENON Collab., Phys. Rev. D **102** (2020) 7, 072004

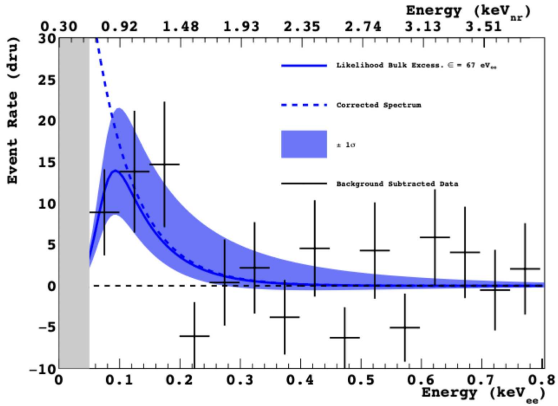
DAMIC Experiment

Prof. Ben Kilminster

39 DAMIC-M (Dark Matter in CCDs at Modane Underground Lab) is an experiment that searches for the dark matter gravitationally bound in our Milky Way through electrical signals produced from its collisions with silicon CCD detectors. This experiment represents a factor of 10 increase in mass, a factor of 10 decrease in the energy threshold, and a factor of 50 decrease in background rates, as compared to the current DAMIC experiment operating in SNOLAB.

https://www.physik.uzh.ch/r/damic

Our group helped found the DAMIC experiment in 2008. For DAMIC-M, we are currently developing a calibration system based on a radioactive isotope, electronics for digitizing the data, imaging software, the control and safety system, and a prototype of the detector with a vacuum interfacing cabling system.



In 2020, DAMIC@SNOLAB found an intriguing 3.4 standard deviation excess while searching for weakly interacting dark matter candidates. The background-subtracted data is shown in black crosses, with the fitted signal as a solid purple line [1].

1. Results on Low-Mass Weakly Interacting ..., DAMIC Collab., Phys. Rev. Lett. **125**, 241803 (2020)

CTA – Cherenkov Telescope Array

Prof. Prasenjit Saha

The Cherenkov Telescope Array (CTA) is a next generation facility for the detection of the most energetic gamma-rays from space, signatures of astrophysical particle acceleration. With more than 100 telescopes located in the northern and southern hemispheres, the Cherenkov Telescope Array (CTA) will extend the currently observable very high gamma ray spectrum by several orders of magnitude. The facility also has the potential to carry out optical intensity interferometry, which is the focus of current activity at UZH.

https://www.physik.uzh.ch/r/cta

Located at the Fred Lawrence Whipple Observatory in Amado, AZ, the pSCT detected gamma-ray showers from the Crab Nebula in early 2020, proving the viability of the telescope design for gamma-ray astrophysics (Image: Amy C. Oliver, Center for Astrophysics | Harvard & Smithsonian).

CTA Homepage https://www.cta-observatory.org/