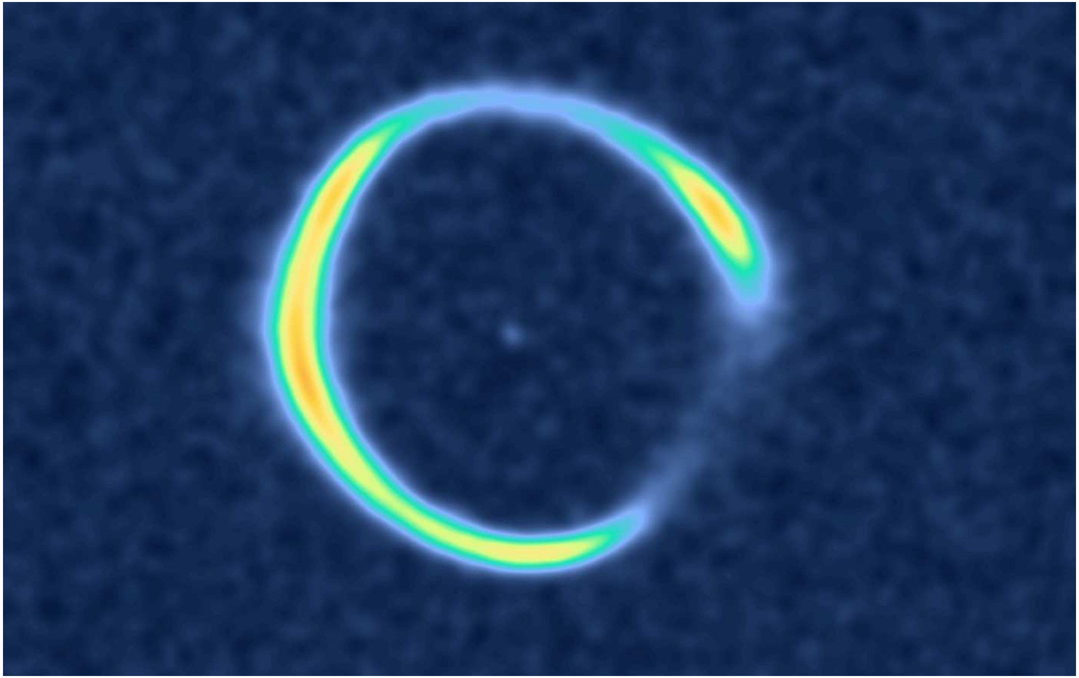
Cosmology, Astro- and Astroparticle Physics



Astrophysics and General Relativity

Prof. Philippe Jetzer, Prof. Prasenjit Saha

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 data and also in the modelling of more accurate gravitational waveforms. The latter results will be used in LIGO and for the future LISA mission.

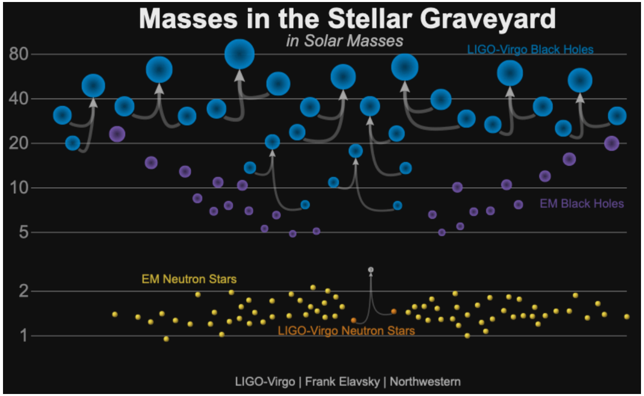
https://www.physik.uzh.ch/g/jetzer

Highlights

The work of the group is focused on the topic of gravitational waves and this both for use with LIGO/Virgo and for the future space mission LISA. Indeed, our group is involved in these collaborations. In the following we briefly describe two main results published in 2019.

In a paper Maria Haney and collaborators derived analytic expressions that provide Fourier domain gravitational wave (GW) response function for compact binaries inspiraling along moderately eccentric orbits. These expressions include amplitude corrections to the two GW polarization states that are accurate to the first postNewtonian (PN) order. Additionally, the fully 3PN accurate GW phase evolution incorporates eccentricity effects up to sixth order at each PN order. Further, a prescription to incorporate analytically the effects of 3PN accurate periastron advance in the GW phase evolution has been developed. The this way computed ready-to-use templates for compact binaries are useful to model moderately eccentric compact binary coalescences.

Michael Ebersold, Yannick Boetzel and collaborators computed the nonlinear memory contributions to the gravitational-wave amplitudes for compact binaries in eccentric orbits at the third post-Newtonian (3PN) order in general relativity. These contributions are hereditary in nature as they are sourced by gravitational waves emitted during



Merging of black holes observed by LIGO and Virgo (blue); masses of black holes detected through electromagnetic observations (purple); neutron stars measured with electromagnetic observations (yellow); and the masses of the neutron stars that merged in the event GW170817, which were detected in gravitational waves (orange). The figure is based on the observations during the first two runs from the LIGO Collaboration.
Figure from LIGO Collaboration, LIGO-Virgo, Frank Elavsky, Northwestern University

the binary's entire dynamical past. Combining these with already available instantaneous and tail contributions they got the complete 3PN accurate gravitational waveform.

Philipp Denzel, together with Saha and other collaborators, studied the effectiveness of different modelling strategies in strong gravitational lensing. The conclusion from this work is that while modelling is becoming increasingly good at reproducing the observables, the non-uniqueness of these models is larger than previously thought.

In a new research direction Saha and collaborators have begun studying future astronomical applications of Hanbury Brown and Twiss interferometry, which shows some promise of imaging at optical wavelengths at resolutions of $\sim 10^{-10}$ radians, which is comparable to the Event Horizon Telescope.

Highlighted Publications:

1. Ready-to-use Fourier domain templates for compact binaries inspiraling along moderately eccentric orbits, S. Tiwari, G. Achamveedu, M. Haney, P. Hemantakumar, Phys.Rev. D**99** (2019), 124008, arXiv:1905.07956.
2. Gravitational-wave amplitudes for compact binaries in eccentric orbits at the third post-Newtonian order: Memory contributions, M. Ebersold, Y. Boetzel, G. Faye, Ch. K. Mishra, B. R. Iyer, Ph. Jetzer, Phys.Rev. D**100** (2019), 084043, arXiv:1906.06263.
3. Lessons from a blind study of simulated lenses: image reconstructions do not always reproduce true convergence,
P. Denzel, S. Mukherjee, J. P. Coles, P. Saha, arXiv:1910.10157

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.

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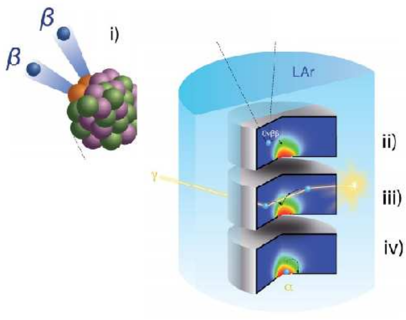
Searches for the neutrinoless double beta decay of ^{76}Ge in GERDA with a sensitivity on the half-life of $T_{1/2}^{0\nu\beta\beta} > 1 \times 10^{26}$ y

Neutrinos are the only fundamental fermions without electric charge and as a consequence, they might be Majorana particles, hence identical to their antiparticles. Majorana neutrinos would lead to nuclear decays that violate lepton number conservation and are therefore forbidden in the SM of particle physics. The so-called neutrinoless double beta ($0\nu\beta\beta$) decay simultaneously transforms two neutrons inside a nucleus into two protons with an emission of two electrons (see Figure). The two electrons together carry the available decay energy ($Q_{\beta\beta}$) and the resulting monoenergetic signal is the expected experimental signature.

The Germanium Detector Array (GERDA) experiment searches for the $0\nu\beta\beta$ decay $^{76}\mathrm{Ge} \rightarrow ^{76}\mathrm{Se} + 2e^-$ with $Q_{\beta\beta} = 2039.061 \pm 0.007$ keV by deploying High-Purity Germanium (HPGe) detectors enriched up to 87% in ^{76}Ge. The experiment is located underground at the Laboratori Nazionali del Gran Sasso (LNGS), at a depth of $\sim$3500 mwe. The HPGe



(i) Artist's view of the $0\nu\beta\beta$ decay of a nucleus by an emission of 2 e^-. (ii to iv) Three BEGe detectors immersed in LAr. Events from $0\nu\beta\beta$ decays deposit energy within a few m^3 in a single detector, while events with coincident LAr scintillation light or with multiple interactions in the Ge detector are classified as background events.

detector array, made of 37 enriched coaxial and Broad Energy Germanium (BEGe) diodes, is operated inside a 64 m^3 liquid argon (LAr) cryostat, which provides cooling and a high-purity, active shield against background radiation. The cryostat is inside a water tank instrumented with photomultipliers to detect Cherenkov light from muons passing through, and thus reduces the muon-induced background to negligible levels. Weekly calibrations of the Ge diodes with ^{228}Th sources are performed to monitor the energy scale and resolution, as well as to define and monitor the analysis selection criteria. The energy resolution (at FWHM) at $Q_{\beta\beta}$ is 3.6±0.1 keV for the coaxial detectors and 3.0±0.1 keV for the BEGe detectors. We have scrutinised a total of 82.4 kg·y of exposure for a $0\nu\beta\beta$ signal. Events with a reconstructed energy of $Q_{\beta\beta} \pm 25$ keV were blinded until the data selection was fixed. GERDA reached an unprecedented low background rate of $\sim 6 \times 10^{-4}$ events/(keV kg y) and thus operated in a background-free regime such that the expected number of background events is <1 in the energy region of interest at the given exposure. No signal was observed, and the derived lower half-life limit is $T_{1/2} > 0.9 \times 10^{26}$ y (90% C.L.). The $T_{1/2}$ sensitivity, assuming no signal, is 1.1×10^{26} y. Combining the latter with those from other $0\nu\beta\beta$ decay searches yields a sensitivity to the effective Majorana neutrino mass in the range 0.07 to 0.16 eV [1].

Highlighted Publications:

1. Probing Majorana neutrinos with double-beta decay, GERDA Collab., Science, Sept 05, 2019
2. Light Dark Matter Search with Ionization Signals in XENON1T, XENON Collab., Phys. Rev. Lett. **123** (2019) 251801
3. First results on the scalar WIMP-pion coupling, using the XENON1T experiment, XENON Collab., Phys.Rev.Lett. **122** (2019) 071301

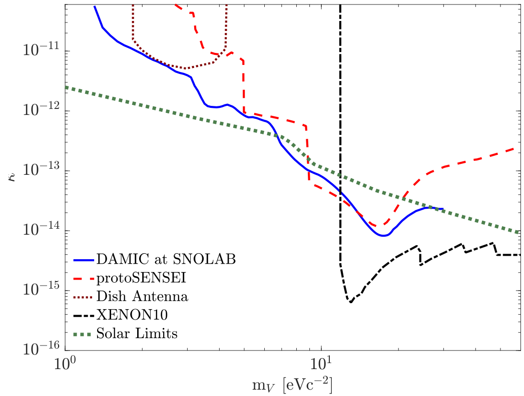
DAMIC Experiment

Prof. Ben Kilminster

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.



Results from DAMIC at SNOLAB, showing sensitivity to electromagneticnic interactions of hidden dark matter with mass between 1 and 10 eV. The blue line shows the interaction rate to which DAMIC-M can probe as a function of dark matter mass.

1. Constraints on Light Dark Matter Particles..., DAMIC Collab., Phys.Rev.Lett. **123** (2019) no.18, 181802.

CTA – Cherenkov Telescope Array

Prof. Florencia Canelli, Prof. em. Ueli Straumann

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.

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

The CTA group at UZH has designed essential elements, including the mirror segment actuator system (AMC), light sensor electronics, safety and power control and mechanics for one of the proposed cameras (FlashCam), and contributes to calibration software development.

CTA will search for new very high energy gamma emitters. It will have a great potential for exploring fundamental frontiers in physics including the extragalactic background light, hypothetical dark matter annihilation signals, and the study of the charged cosmic ray acceleration processes. In 2019, one of the first FlashCam cameras was successfully installed at the HESS site (a currently operational Cherenkov Telescope experiment) and has been performing well.

FlashCam cameras installed at the HESS site in Namibia.

Highlighted Publications:

1. Potential for measuring the longitudinal and lateral profile of muons in TeV air showers with IACTs, A. Mitchell *et al*, Astroparticle Physics **111** 23-34 (2019)