Research objectives. The goal of this project is to describe the time evolution of the star formation in the Universe, as traced by the far-infrared/sub-millimeter (far-IR/sub-mm) observations (sensitive to the star formation obscured by the interstellar dust). The main question that I will aim to answer is: 'How did efficiency in forming stars evolved across the history of the Universe?'. During the project, I will first determine the average 'efficiency' of the Universe in forming stars in terms of the so-called star formation rate density (SFRD) – ie. how many stars, on average, have been formed per unit time and volume in the Universe at a given epoch. In order to go deeper, I will also describe how the star formation efficiencies in galaxies evolved at the given moment in the history of our Universe as a function of their stellar mass.

Project methodology. In order to quantify the average star formation rates in the Universe, one requires large enough maps of the sky, in order to collect samples of galaxies which may be considered representative of the whole Universe. In addition, the maps have to be deep enough, so that both, the faint and the bright galaxies are observed in sufficient numbers. The first task will be, therefore, to use the largest high-resolution sub-millimeter data, collected to date with the Atacama Large Millimeter Array (ALMA), to construct luminosity functions, describing the volume densities of galaxies at a given time in a history of the Universe. Applying appropriate conversions (performed with the help of well-known calibrations), the time evolution of the efficiency of our Universe in forming stars will be determined. Since most galaxies cannot be directly detected in the sub-mm waves, I will also quantify the contribution to the SFRD of the Universe from the fainter populations by stacking (averaging fluxes from many sources) in the far-IR/sub-mm maps, and thereby acquiring average star formation values for sources, for which no such measurements can be done directly. During stacking, the average fluxes will be determined for groups of galaxies sharing similar physical properties, i.e. stellar masses. During this process a number of relationships between the physical properties and far-IR/sub-mm luminosities will be precisely calibrated out to the times when the Universe was only about 10% of its current age.

Motivation. One of the main goals of the observational cosmology is to describe the time evolution of the star formation in the early Universe. Being one of the most fundamental observables, it is one of the basic outputs of simulations of the evolution of the entire Universe. In addition, the luminosity functions, required for the determination of the SFRD, are regularly used to test current cosmological models. Their precise description is, therefore, crucial not only for the observational astronomy, but also for theoretical models describing the evolution of life in our Universe. Problem is, that performing these tasks requires access to large enough data sets in both the ultraviolet (UV; sensitive to the direct starlight) and the far-IR/sub-mm (tracing dust emission) waves. Due to the limited access to the sub-mm imaging, the time evolution of the SFRD, as well as the luminosity functions, is very difficult to establish, with the literature largely disagreeing between various works.

The SCUBA-2 instrument mounted on the James Clerk Maxwell Telescope in Hawaii is one of the biggest facilities in the world observing at sub-mm wavelengths and as such produces maps which can be very effectively used for the determination of the dust-obscured star formation rates. The largest to date images are currently being carried out as a part of a number of international surveys, all of which I am an active member of. With the help of the high-resolution ALMA data, as well as ancillary optical catalogs, the current knowledge of the star formation in the Universe can be largely improved.

Expected results. The high-resolution ALMA data (consisting of over 500 galaxies) allows for the determination of the contribution to the overall star formation density of the Universe from the brightest far-IR/sub-mm galaxies. Stacking (averaging fluxes from many sources) that will be done in the largest to date SCUBA-2 maps will account for the contribution from the faint objects. Both of the above data sets will allow me to construct a function, which will describe how many galaxies of a given luminosity (intrinsic flux) reside in a given volume of the Universe at the particular time of its evolution – the so-called luminosity function. The current state of knowledge describes the evolution of the far-IR/sub-mm SFRD out to about two billion years after the Big Bang. With the sub-mm maps available in this project I will be able to extend this by about one billion years.