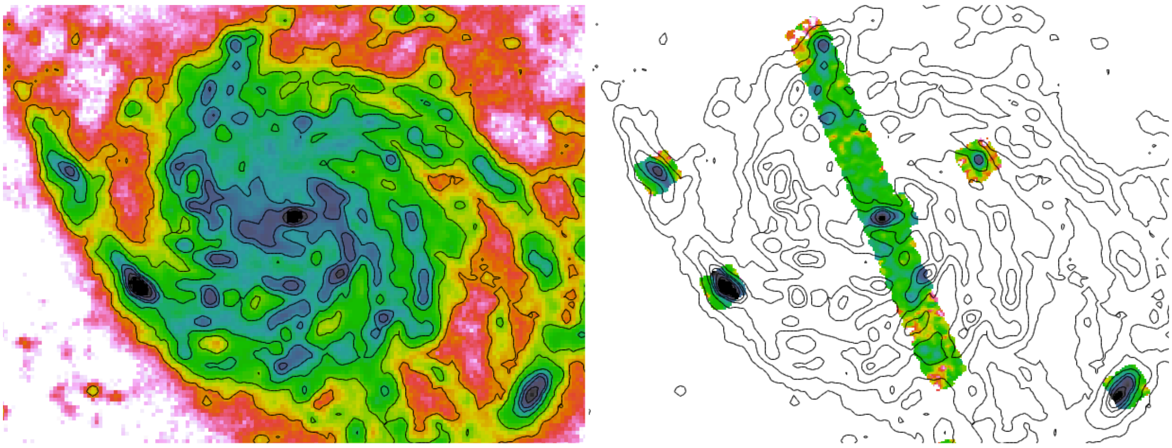
The goals of the DEEPKINGFISH (Dust Evolution and the Efficiency of the Photoelectric Effect from KINGFISH) project were to characterize the properties of interstellar dust in a sample of nearby galaxies and relate those properties to the efficiency of photoelectric heating traced via the far-infrared cooling lines of carbon and oxygen relative to the total infrared emission from dust. The dataset used for this study was the observations of 61 nearby galaxies from the KINGFISH key program on the *Herschel* Space Observatory (Key Insights into Nearby Galaxies: A Far-Infrared Survey with Herschel, PI R. Kennicutt). During the period of the project (October 2011 till October 2013), the researcher, Dr. Karin Sandstrom, led a detailed study of dust properties in the KINGFISH galaxies and played a key role in analyzing the KINGFISH cooling line measurements. Dr. Sandstrom also led a group that pursued similar research goals using observations of the Andromeda galaxy, which she proposed for and obtained. In the following we outline the key results of Dr. Sandstrom's work on DEEPKINGFISH.

The logo of the KINGFISH key program.

The majority of neutral gas in the interstellar medium of a galaxy is heated by the photoelectric effect, wherein ultraviolet photons are absorbed by a dust grain, eject an electron from the grain and then the electron collides with gas particles, heating up the gas. The efficiency of the transformation of UV photons into heating depends on the abundance of dust relative to gas, the properties of dust grains and the spectrum of the UV radiation field. The efficiency of the photoelectric effect can be traced observationally by comparing the total cooling rate of the gas, quantified by the sum of the flux emerging in the two dominant cooling lines [CII] 158 μm and [OI] 63 μm, relative to the amount of emission from the dust. The focus of Dr. Sandstrom's work was to measure dust properties and compare with cooling line emission.

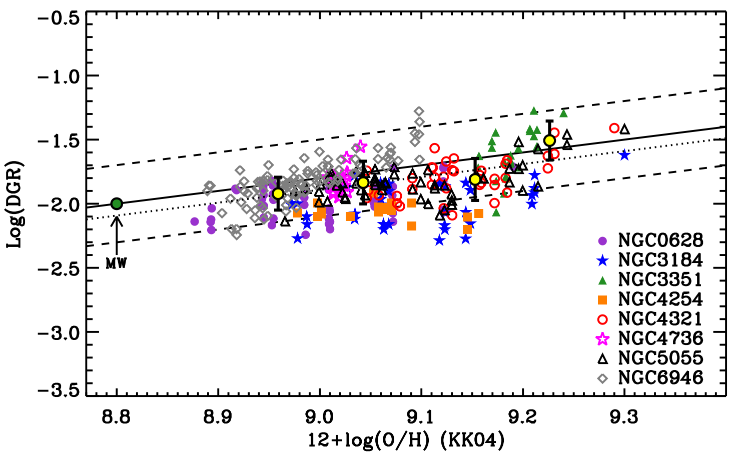


An example of the KINGFISH observations for the galaxy M101. On the left is an image of the 250 μm emission, which traces the mass of dust in the galaxy. On the right is the [CII] 158 μm cooling line emission. The contours in both panels are from the 250 μm map. Using the KINGFISH observations one can trace the amount of dust and the heating rate of the gas.

The first step in this project was to measure the dust-to-gas (DGR) ratio in the KINGFISH galaxies. This parameter can be measured by comparing maps of dust mass, derived from modeling the far-infrared spectral energy distribution (SED) of dust, to maps of gas mass, constructed by combining maps of atomic hydrogen and molecular hydrogen. Dr. Sandstrom played an important role in the dust SED modeling, in collaboration with researchers at Princeton and other members of the KINGFISH team. The results of this part of the research project are published in a paper by Aniano et al. (2012). The resulting maps of dust mass surface density in the KINGFISH galaxies were crucial for the subsequent step of measuring the DGR. A key aspect of measuring DGR is tracing the amount of molecular hydrogen in the galaxy. Because of the relatively high temperatures to excited the rotational lines of the H2 molecule, it is difficult to use it to directly track the amount of molecular gas. Instead, the second most abundant molecule, carbon monoxide (CO) is typically used. The observed strength of CO rotational lines is converted into measurements of molecular gas mass using the “CO-to-H2” conversion factor. A key issue for studies of DGR is the fact that this conversion factor can vary and lead to systematic uncertainties in assessing the total amount of gas.

Dr. Sandstrom’s major work over the last two years has been to develop and apply a new technique to simultaneously measure the DGR and conversion factor for CO. This innovative technique uses the fact that the *Herschel*-based maps of dust mass surface density are created at much higher resolution that previous versions could be. These maps can be combined with matched resolution atomic hydrogen and CO maps and both DGR and the conversion factor can be determined. Dr. Sandstrom developed this technique and performed a thorough exploration of its effectiveness. She applied the technique to the subset of galaxies observed by KINGFISH and the gas surveys THINGS (The HI Nearby Galaxy Survey; PI F. Walter) and HERACLES (the HERA CO Line Emission Survey; PI A. Leroy). The two gas surveys were led by MPIA researchers, including the scientist-in-charge of DEEPKINGFISH, Dr. Fabian Walter.

The results of Dr. Sandstrom’s study have been published in Sandstrom et al. (2013) in *The Astrophysical Journal*. This journal article has already generated a great deal of interest in the community and has been cited more than 20 times since its publication. The key findings are that the conversion factor for CO can very by large amounts in nearby galaxies, specifically decreasing well below the standard value in galaxy centers. This has a major impact on the assessment of the DGR in these regions. The DGR values found in the KINGFISH galaxies show a very good correlation with the metallicity of the gas. This is to be expected if a constant fraction of the available heavy elements are in dust grains.



The dust-to-gas ratio (DGR) as a function of metallicity measured the KINGFISH galaxies using the technique developed by Dr. Sandstrom as a part of DEEPKINGFISH. The different colored points represent different galaxies. The dotted line represents the best fit to the data. The solid line is a linear relationship between metallicity and DGR, normalized to match the Milky Way’s metallicity and DGR, with a factor of two above and below shown in dashed lines.

The next part of the project involved comparing the dust properties with cooling line emission. Dr. Sandstrom participated in an early investigation of this subject, published in Croxall et al. (2012). She has been working on a more in depth study that should be published in the next year. Dr. Sandstrom has also supervised a Ph.D. student at MPIA who has been comparing dust properties to [CII] emission in the Andromeda galaxy. The results of that project show that the efficiency of the photoelectric effect in that galaxy may be related to DGR and metallicity. Finally, Dr. Sandstrom led a program of *Herschel* observations to target very low metallicity galaxies where DGR is low and dust properties change. These observations were obtained in spring 2013 and analysis is currently underway.