Abstract. Due to its location and climate, Antarctica offers unique conditions for long-period observations across a broad wavelength regime, where important diagnostic lines for molecules and ions can be found, that are essential to understand the chemical properties of the interstellar medium. In addition to the natural benefits of the site, new technologies, resulting from astrophotonics, may allow miniaturised instruments, that are easier to winterise and advanced filters to further reduce the background in the infrared.

1 Introduction

An observatory in Antarctica offers the potential to study many astrochemical signatures, such as diffuse interstellar bands (DIBs) and molecular properties of the interstellar medium (ISM). Given, that Antarctica offers one of the best atmospheric transmissions from the ground (Lawrence 2004), these observational studies can be carried out at many wavelengths, with particular benefits in the infrared. As the thermal background is much reduced (e.g. by a factor of 100 at 3 microns), the observational window in Antarctica is wider as compared to tempered sites. In addition to the natural low thermal-background, recent developments in Fiber-Bragg-Grating technologies (Bland-Hawthorn et al. 2009), allow a sophisticated filtering of individual OH-emission lines and thus a further suppression of the infrared sky background.

In a collaboration between the Astrophysical Institute Potsdam (AIP) and the Physical Chemistry Group of the University of Potsdam (UPPC), interdisciplinary research in fiber-spectroscopy and sensing (Roth et al. 2008) as well as in astrophotonics and astrochemistry is being combined. The aims are twofold: to develop new astrophysical instrumentation based on photonic technologies and to
study properties and reactions of relevant molecules and ions in the laboratory. Discussed below are the potential links of these R&D efforts with respect to an Antarctic observatory.

2 Astrochemistry

In astrochemistry, the chemical reactions of atoms, ions, molecules and dust particles, that are present in the interstellar medium (ISM) are being studied. In particular, in areas with low temperatures \((10 \, K < T < 100 \, K)\), a relatively high density \((> 100 \, cm^{-3})\) of these particles exist, which leads to rich and complex chemical reactions. More than 100 different molecules (and their respective ions) are observable in these areas of the ISM. The study of the formation of complex molecules or the role of dust particles as interstellar reactors are essential topics to understand the chemical evolution, the formation of stars and planets and the creation of the chemical building blocks of life.

An Antarctic observatory offers the option to spectroscopically detect molecules in the ISM from the UV to THz spectral range. This topic is related to a science case, that was identified by the ARENA submm-working group: “Measuring the physical and chemical properties of the interstellar medium in our Galaxy, in the Magellanic clouds and nearby galaxies.”

Of particular interest are observations of Diffuse Interstellar Bands (DIBs). These DIBs are absorption features, produced as starlight passes through interstellar matter. Despite the fact, that the first detections of DIBs go back to the 1920s, and that about 700 features are known so far, the identification of their nature is one of the longest-lasting problems in astronomical spectroscopy.

In the current understanding, DIBs are probably caused by carbon chains (Maier et al. 2004) or Polycyclic Aromatic Hydrocarbons (PAHs), which are complex organic molecules that are made up from 6 to 60 carbon-atoms. PAH are present in the ISM and can satisfy the abundance requirements for the DIBs (Snow, Bierbaum 2008). PAH cations are known to have rich optical and IR spectra and according to laboratory experiments at least some overlap with observed DIBs. Fulara et al. (1993) present laboratory evidence that highly unsaturated hydrocarbons with carbon numbers 6-12 may be the carriers of some of the DIBs in the range 480-1000 nm. While PAH may be good candidates to explain (some) DIB features, it is unclear, if PAHs form in stars or by ion-molecule reactions within the ISM. Laser-based ion mobility spectrometry is a suitable experimental tool for the investigation of the formation of large anionic PAH clusters (Beitz et al. 2006) and PAH-mediated ion-molecule reactions (Löhmansroben et al. 2006), that are central issues in astrochemistry.

The detection of diffuse interstellar bands (DIBs) at 5780 and 5797 \(\AA\) in the Small Magellanic Cloud and the variation of the 6284 \(\AA\) DIB toward several targets in the Large Magellanic Cloud (Ehrenfreund et al. 2002) is of particular interest, given the good visibility of these targets from Antarctica.

Further spectroscopic observations and monitoring of possible variations, in particular at unexplored areas, are needed, “accompanied by progress in the un-
derstanding of the physical and chemical properties of molecules and solids and of the physical processes and chemical reaction rates in the interstellar medium, by means of theoretical calculations and laboratory experiments.” (see Astronet Science Vision 4.3.3.)

3 Astrophotonics

Astrophotonics is a relatively new research field with the aim to meet the increasing requirements towards astronomical instrumentation. Astrophotonics investigates new technologies (for a review see Bland-Hawthorn, Kern 2009), to improve and miniaturise instruments by replacing classical optical components with photonic devices.

Major developments during the last years are based on the manipulation and application of light-guides and optical fibres. Amongst others, these R&D efforts include photonic crystal fibres and multi-mode to single-mode couplers in “pho-tonic lanterns” (Noordegraaf et al. 2009). Using lasers, it is possible to inscribe refractive index changes into optical fibres (Thomson, Kar, Allington-Smith 2009) and thus to create periodic structures along the fiber axis. These Fiber-Bragg Gratings (FBGs) act as highly complex and sophisticated filters. A demonstrated application in astronomy is the filtering of unwanted atmospheric OH-emission lines with the effect to reduce the IR-sky background (Bland-Hawthorn et al. 2009). The use of the FBG-technology to eliminate individual emission lines, combined with the natural low thermal background, makes an Antarctic observatory equipped with instrumentation featuring OH-surpression fibres a unique facility to spectroscopically observe the NIR-universe.

In another development, the properties of lasers and photonic crystal fibres are combined to create super-continuum white light sources and laser-frequency combs (Mandon et al. 2007). The latter allows precise and long-term stable calibration devices for high-resolution spectroscopy (Murphy et al. 2007). Any dedicated spectrograph at an Antarctic observatory, that either targets the detection of extra-solar earths or tries to measure the expansion of the universe directly, would require such advanced calibration technology.

Planar waveguides offer the potential to develop Integrated Photonic Spectrographs (Bland-Hawthorn, Horton 2006). These miniaturised spectrographs “on a chip” would be much easier to transport, to install, to thermalize and operate at Antarctic conditions than classical bulky optics. Given their small sizes, they also could be replicated in numbers, creating a high-multiplex factor without significantly adding to the volume or weight budgets or the transport costs.

In addition, the above mentioned photonic technologies can be incorporated into fiber-based multi-object or integral-field spectrographs and thus combine the general advantages of imaging spectroscopy (Kelz 2007) with OH-surpression (Ellis et al. 2009), and possibly, frequency comb calibration units to create ultra-stable, spectrographs with high-multiplex for Antarctica. While offering almost spacelike conditions in certain wavelength regimes, that are important for the study of astro-chemical processes, these facilities also benefit from ground-based
advantages, such as lower costs, shorter implementation schedules, accessibility for maintenance, repairs and upgrades to ensure state-of-the-art instrumentation.

4 Summary

An Antarctic observatory can serve as complementary facility to much larger projects, such as SOFIA, ALMA, Herschel, SKA to study molecules and chemical processes in the ISM across a wide wavelength range. On the other hand, offers the development of astrophotonical technologies particular benefits for any Antarctic observatory, such as miniaturisation of instrumentation or OH-surpression filters.

The interdisciplinary approach at Potsdam targets research in both areas of astrophotonics and astrochemistry. It is, in accordance with considerations of the Astronet Science Vision and the Infrastructure Roadmap, aimed to combine observations from the UV to the THz spectral range with experimental techniques and theory to investigate ISM-relevant molecules and chemical reactions.

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