PILOT: Measuring the Far-Infrared Red polarization of the diffuse Interstellar Medium

J.-Ph. Bernard[a], P. Ade[b], P. deBernardis[c], P. Hargrave[b], B. Leriche[d], Y. Longval[d], C. Marty[a], S. Masi[c], F. Pajot[d], L. Rodriguez[e] and the PILOT team

[a] Centre d'Etude Spatiale du Rayonnement, Toulouse, France, [b] Cardiff University, Cardiff, UK, [c] LaSpienza University, Rome, Italy, [d] Institut d'Astrophysique Spatiale, Orsay, [e] Centre des Etudes Atomiques, Saclay, France

***Abstract*— Measuring precisely the faint polarization of the Far-Infrared and sub-millimetre sky is the next observational challenge of modern astronomy. In particular, detection the B-mode polarization from the Cosmic Microwave Background (CMB) shall reveal the inflationary periods in the very early universe. Such measurements will require very high sensitivity and very low instrumental systematic effects. As for measurements of the CMB intensity, sensitive measurements of the CMB polarization will be made difficult by the presence of foreground emission from our own Milky Way, which is stronger than the faint polarized cosmological signal. Such foreground emission will have to be understood very accurately and removed from cosmological measurements. This polarized emission is also interesting in itself, since it brings information relevant to star formation processes, about the orientation of the magnetic field in our Galaxy through the alignment of dust grains. I will first summarize our current knowledge in this field. I will then describe the PILOT balloon-borne experiment project, which is dedicated to measuring precisely the polarization of faint diffuse dust emission from our Galaxy in the Far-Infrared.**

I. Polarized dust emission

THe InterStellar Medium (ISM) is populated by very tenuous gas (essentially neutral Hydrogen, but also more complex molecules) and dust grains of sub-micron sizes which are composed of solid, amorphous silicates and graphite. These grains absorb starlight mainly in the UV and visible, are heated to 15-30 K in the diffuse ISM and radiate continuum emission in the Far-Infrared to Sub-millimeter wavelength range, where they dominate the total sky emission. Dust particles are believed to have somewhat elongated shapes. In the presence of the faint magnetic field (a few micro-gauss) that pervades in the ISM, several processes contribute to make dust grains rotate about their minor axis, which then partially align with respect to the magnetic field lines. This partial alignment of dust grains causes preferential emission along the major axis of the grains, so that a fraction of the thermal emission is linearly polarized in a direction orthogonal to the magnetic field line, as projected on the sky. Similarly, dust absorption is also polarized. Measuring the polarized emission and absorption by dust grains is important for CMB science, but also because it should reveal a new aspect of dust physical properties and is a way to trace the geometry of the magnetic field in space, with obvious links to the star formation process.

II. The PILOT experiment

PILOT (Polarized Instrument for the Long-wavelength Observations of the Tenuous ISM: http://pilot.cesr.fr) is a project of a balloon-borne astronomy experiment to study the polarization of dust emission in the diffuse ISM in our Galaxy.

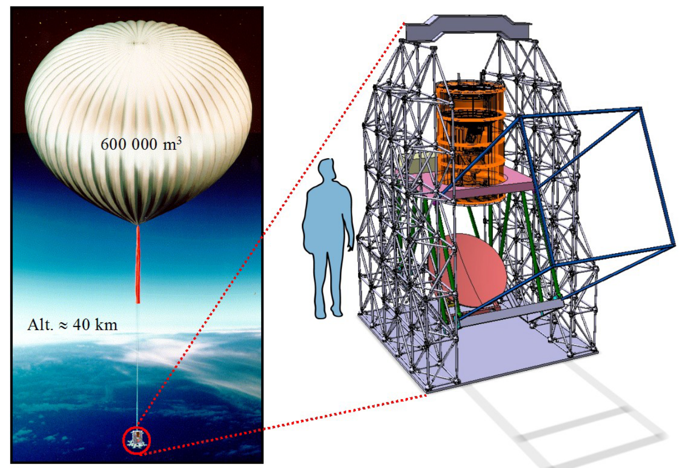

Figure 1: Schematic view of the Pilot gondola. The cryostat (cyclinder on top) and the primary mirror are attached to the pointed load, which can rotate around its elevation axis in order to change the elevation of the submm optical axis. Motion around the flight chain will be ensured by an azimuth swivel (not shown). Optical baffles and thermal protection screens surrounding the experiment are not shown..

The PILOT instrument will allow observations in two photometric channels at wavelengths 240 µm (1.2 THz) and 550 µm (545 GHz) at an angular resolution of a few arcminutes. We will make use of large format bolometer arrays, newly developed for the PACS instrument on board the Herschel satellite. With 1024 detectors per photometric channels and photometric bands optimized for the observation of dust emission, PILOT is likely to become the most sensitive experiment for this type of measurements. We propose an innovative method to measure polarization, inspired from that used with individual polarization sensitive bolometers, but adapted for the use of filled bolometer array. The sensitivity of the PILOT experiment will surpass that of previous experiments by a factor more than 20 for a given column density of interstellar matter. PILOT will also be the only astronomical instrument able to measure the polarization properties of dust emission in the FIR in the near future, since none of the Herschel satellite instrument will be sensitive to polarization.

978-1-4244-2120-6/08/$25.00 ©IEEE.

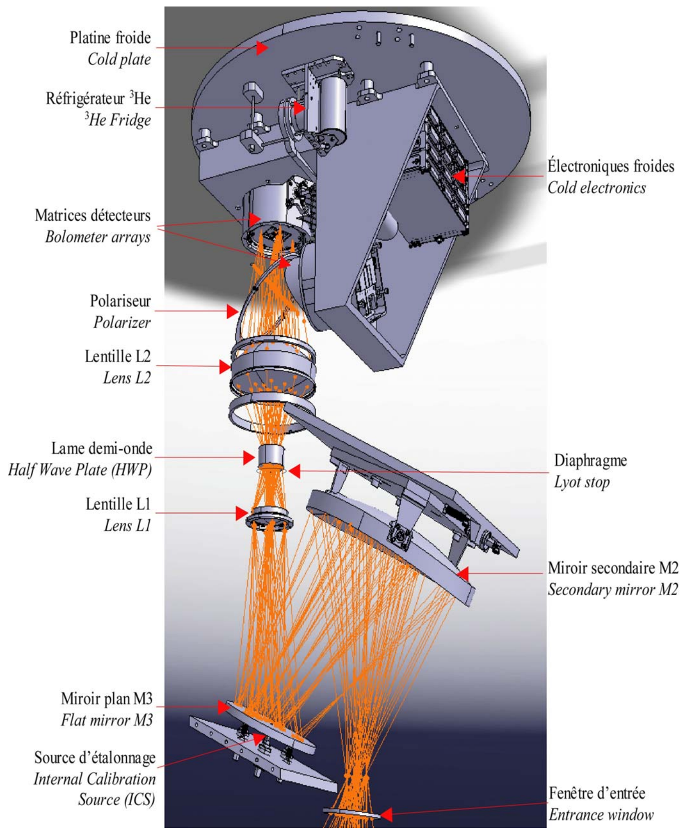

Figure2 : Schematic view of the Pilot cold optics: After being focalized on the entrance window of the cryostat, the incoming beam goes through a reimaging optics containing a step-by-step rotating Half-waveplate. The two orthogonal polarization components are splitted by a tilted polarizer towards the transmission (top) and reflection (left) bolometer array housings.

The polarization will be measured using a combination of a rotating half-wave plate and the fixed analyzer grid positioned in front of the detector housings. This is a classical design in which the polarized part of the incident light is phase-shifted by the wave-plate and selectively transmitted by the analyzer. Such systems are often used at rotation frequencies of a few Hertz followed by in-phase analysis of the bolometer signal. However, such a use has one main disadvantage: Given that the instrumental background can easily be 10^5 times higher than the polarized signal to be measured, any SLIGHT fluctuation of the background introduced by the rotating plate, such as anisotropies of the plate transmission, can easily produce a fake signal in excess of the astrophysical polarized signal. If well adapted to fast readout single bolometers, this technique is not necessarily optimal for slower bolometer arrays and fast scanning experiments. For Pilot, we plan to use a stepping wave-plate, the angular position of which (at least 2 are necessary to measure polarization) will be changed at the end of each scan on the sky. This measurement method is similar to what is achieved using Polarization Sensitive Bolometers (PSBs) or Orto-Mode Transducers (OMT) pairs. The I and Q Stokes parameters are measured at a given time, through a differential measurement and the I and U parameters are then measured at a later time. In our case, the time difference between the two measurements is the time separation between successive scans. This is equivalent to modulating the polarized signal at a very low frequency, which is well below the scanning frequency. The background signal should be slightly different between the different positions of the plate, but this will contribute a constant offset between individual scans, which can be removed during data processing. A second advantage is that, individual scans being obtained at a constant direction of the analyzer, redundancy in the scans can be used to intercalibrate the response of individual bolometers (response flat-field) at any time. This will be used to monitor the possible variations of the response flat-field. In addition, the Pilot optics will be equipped with an internal calibration source that will be used at the end of each scan on the sky, in order to calibrate changes in the response flat-field.

However, the above measurement strategy is not necessarily immune low frequency drifts of the bolometer noise (so called 1/f noise) or fluctuations of the residual atmospheric signal. Results of numerical simulations for these contributions indicate that they will not affect our ability to recover the polarization intensity, partly because the 1/f noise of the bolometers used is low.

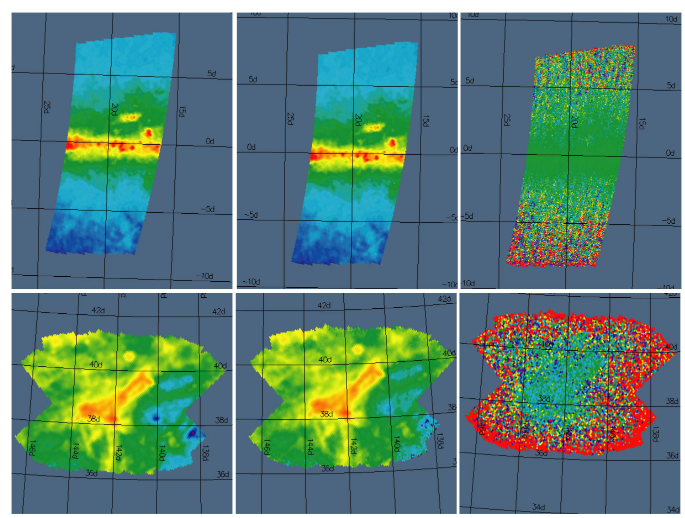

Figure 3: Simulations of the observations that will be obtained with Pilot at 240 μm within one hour of observations toward the galactic plane (upper panel) and a diffuse cirrus cloud (lower panel). The simulation includes realistic noise properties for the bolometer arrays. The left panels show the input map, the central panels show the reconstructed intensity map, the right panels shows the reconstructed polarization degree which, in the simulation, was assumed to be 5 % of the total intensity. The lower-upper cuts on the right panel is 4-6 % and 3-8 % for the galactic plane and cirrus respectively.

978-1-4244-2120-6/08/$25.00 ©IEEE.