Herschel Lifetime Estimate from Cooler Recycling

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Draft	07-Sep-11			Initial version
Issue 1	22-Sep-11			Proposed changes by G. Pilbratt and A. Poglitsch implemented

Table of Content

1 Scope

This document is meant to describe the method and report the status of the expected Herschel lifetime derived from cooler recycling procedures of the PACS and SPIRE instrument.

2 Reference Documents

RD-1 "The Observed Properties of Liquid Helium at the Saturated Vapor Pressure", Russell J. Donnelly and Carlo F. Barenghi, http://pages.uoregon.edu/rjd/vapor1.htm
RD-2 "Heat Capacity of Aluminum between 0.1K and 4.0K", N. E. Philips, 1959, Phys. Rev. 114, 3

3 Description of the Method

Inserting a defined amount of energy ΔE into the Herschel LHe bath should raise its temperature by ΔT, where $\Delta T = \Delta E/C$ with C representing the heat capacity of the HeII in the tank. C is obviously proportional to the LHe mass which is still inside the HTT. If ΔE is known it is a direct measure of the LHe mass. This is the principle of the Direct Liquid Content Measurements (DLCMs) carried out on few occasions during the mission. If ΔE is not known but constant (see below) for a series of measurements with a constant decrease of LHe mass per unit time, an analysis of the temperature changes after the heat injection will fit a curve from which the time when there is no LHe left can be extrapolated. Predicting when this will happen is the objective of the present analysis.

Below the λ-point of liquid helium (2.17K) its heat capacity changes rapidly with temperature ($\sim T^{5.5}$ at 1.64K, see RD-1). For a constant ΔE and with $\Delta E = \int C(T)\,dt \sim m\,(T_2^{6.5}-T_1^{6.5})$, the mass of liquid helium (m) in the tank is proportional to $1/(T_2^{6.5}-T_1^{6.5})$, where T_1 and T_2 represent the temperatures of HeII before and after the heat transfer respectively. The heat capacity of the tank and its support structure is being neglected here, because its heat capacity (see RD-2) is too small compared to the heat capacity of HeII for any significant contribution. With the (almost) infinite thermal conductivity of HeII, any gradient in the tank temperature would be levelled out very rapidly.

At the point in time during a cooler recycling, when all ^{3}He inside the cooler has been condensed into the evaporator by heating the pump, the pump is being reconnected to the HTT to prepare it again for the adsorption of ^{3}He to start the sub-K operation of the evaporator. We do not know the precise value of ΔE, however we know that it is very much constant because the recycling procedure of PACS runs as a command procedure with fixed timing and therefore when the hot pump is being connected to the HTT a highly reproducible amount of energy is being transferred into the tank. In the case of SPIRE, where the cooler recycling procedure does not run within a fixed time, there may be some small scatter in the energy deposit, however on average it should also be rather similar. The temperature measurements on the HTT sensor T101 shortly before (T_1) the connection of the pump and after all energy has been transferred (T_2) are used to evaluate the $1/(T_2^{6.5}-T_1^{6.5})$ trend.

4 Data Preparation

- Extract the following telemetry parameters from the HPSDB and store them as FITS files:
  KD200303 C100_0_T101 (= Level 0 temperature sensor [K])
  PM415410 BOL_HEAT_SP_SWT (= PACS sorption pump switch current [mA])
  SMH0A520 SPHSV (= SPIRE sorption pump switch voltage [mV])

5 Data Processing and Analysis

The FITS files for each of the selected HK parameters and for each OD are generated within HIPE and read into an IDL session. The timeline of both sorption pump switches is then searched for transients (<10 → >500 for SPIRE and <0.1 → >1.3). Figures 1 and 2 show typical cases for sorption pump switch activations. For each transition the following calculations are being stored:

T_1 = mean temperature across the time interval 60 sec – 260 sec after the detected heat switch transition.

T_2 = mean temperature across the time interval 1360 sec – 1560 sec after the detected heat switch transition.

f(m) = $1/(T_2^{6.5}-T_1^{6.5})$, the quantity of interest for the purpose of this analysis

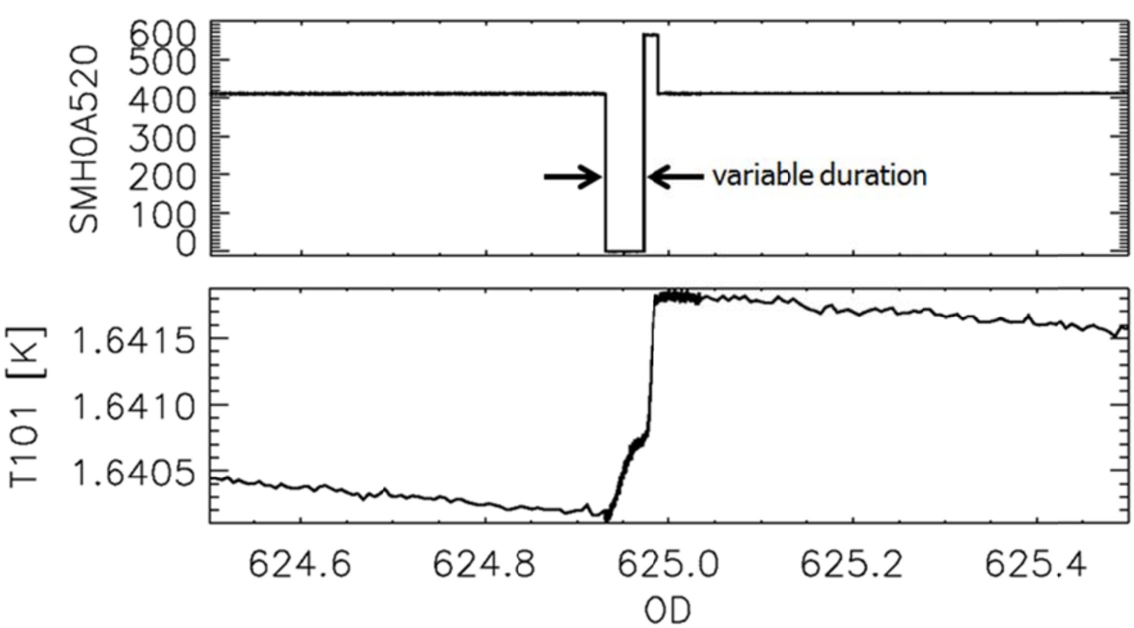

Figure 1: Example of SPIRE sorption pump switch actuation and respective temperature evolution at level 0.

Figures 3 and 4 illustrate the level 0 temperature evolution and mark the time intervals during which the average temperature readings are taken.

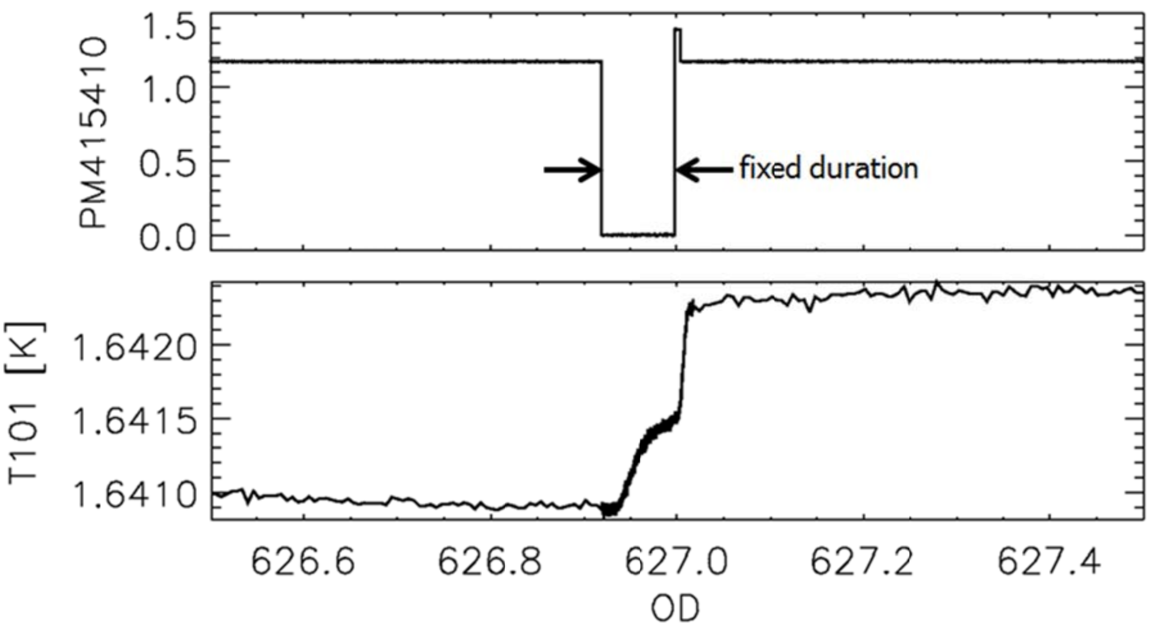

Figure 2: Example of PACS sorption pump switch actuation and respective temperature evolution at level 0.

The following criteria are being applied to select “valid” cooler recycling procedures for further analysis:

- The temperatures from a recycling procedure are only included in the analysis if more than 58 hours have elapsed since the last recycling. This rule makes sure that all cases where the evaporator was not yet empty are excluded. The energy deposit into the HTT is significantly larger once the evaporator hasn’t been empty before.
- The temperatures from parallel recycling procedures are only taken for PACS. Due to the commanding sequence, the SPIRE sequence overlaps with PACS and one cannot determine a reproducible ΔT for SPIRE in this case. However since PACS is the last in the procedure sequence, the pump connection to the HTT provides still a clean temperature transit and is therefore included in the analysis.
- All data before OD90 are masked out to ensure that the thermal settling effects of the Herschel cryo-system after launch have been concluded and are not affecting our analysis.

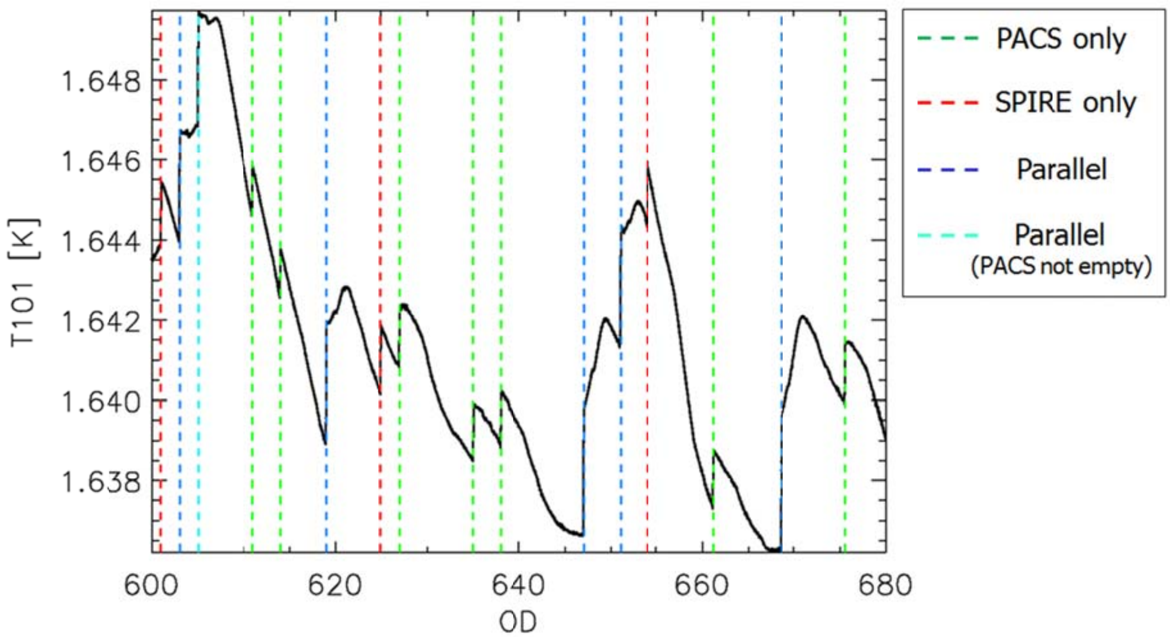

Figure 3: Typical temperature evolution at level 0. Only cooler recycling procedures or DLCMs cause noticeable thermal events. The different types of recycling procedures are marked by the dashed lines.

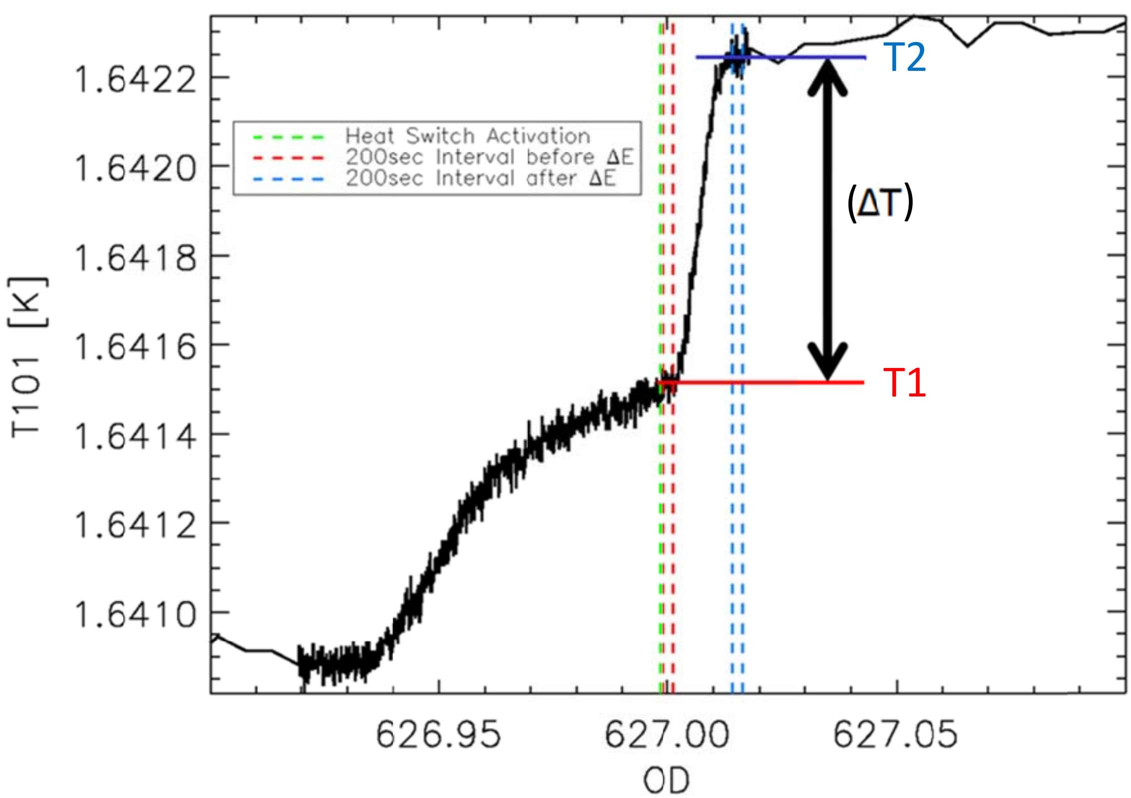

Figure 4: Example of a measurement of the temperature rise ΔT during a cooler recycling

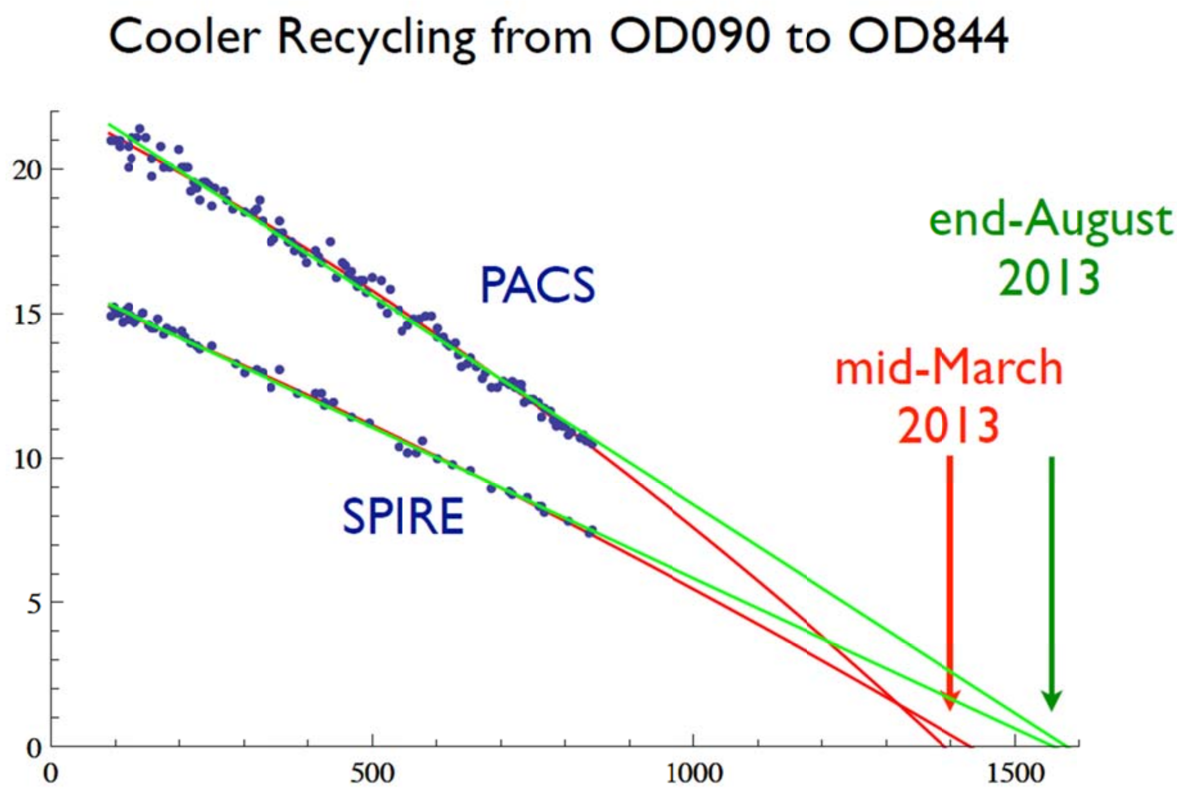

Figure 5: Plot of $1/(T_2^{6.5}-T_1^{6.5})$ for PACS and SPIRE against days after launch (blue dots). A second order fit to the data (solid red lines) and a first order fit (solid green lines) as extrapolation for each of the measurement entities is overplotted. The second order fit was introduced since the measured points didn't seem to fall on a straight line.

6 Discussion

The consumption of LHe in the Herschel cryostat is driven mainly by thermal/radiative conduction from the support structures and shields, respectively, but also by instrument dissipation. After the initial rather quick general warming of the satellite until about OD245, the CVV temperature continued to increase - however, much slower, peaking around OD607 (sensor T912), and the relative variations converged closer and closer to the seasonal variations imprinted by the Herschel orbit around the sun. A change in CVV temperature should also cause slight variations in the LHe mass flow. Other thermal analysis (e.g. SPIRE JFET switch-ons, G. Pilbratt priv. comm.) suggest that the helium mass flow through the vent line is rather constant throughout the mission. Both, the changes in CVV temperature and the SPIRE JFET switch-ons have not yet been converted to quantitative mass flow predictions. A constant mass flow obviously means in turn that the decrease in LHe mass should follow mostly a linear trend in time. Fitting the data with a straight line is however clearly less good than a second order polynomial fit. The extrapolations given in figure 5 are therefore providing quite different End-Of-Helium dates. The reason for the non-linear behaviour, suggesting a non-constant mass flow with time is not yet understood.