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The chromosphere of α Cen A as seen by the Herschel Space Observatory

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Abstract

Chromospheres and coronae are common phenomena on solar-type stars. Understanding the heating of those layers requires the direct access to the relevant empirical data. In particular, the chromospheric temperature minimum, i.e. the region of the atmosphere where the temperature undergoes a reversal and starts increasing to reach values of the order of MK in the corona, can be observed directly in the far infrared and in the submillimetre spectral regime. In this paper we present the results of the observations obtained in those ranges of the solar twin α Cen A. Similar to the Sun, the far infrared emission of this star originates in the temperature minimum above the stellar photosphere. To our knowledge, this is the first time a temperature minimum has been directly measured on a main-sequence star other than the Sun.

This contribution is a summary of the the results presented in "α Centauri in the far infrared. First measurements of the temperature minimum of a star other than the Sun" [9] based on results from the *Herschel* Open Time Key Project DUNES and APEX/LABOCA observations.

1 Introduction

The nearest stellar system to the Sun, α Cen, is located at a distance of 1.3 pc ($\pi = 747.1 \pm 1.2$ mas). The physical binary is composed of two solar-like stars, the brighter of which, α Cen

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A (HIP 71683, HD 128620), a G2 V star, is often considered a "solar twin": $M = 1.105 M_\odot$, $T_{\rm eff} = 5824$ K, $\log g = 4.306$ and Age$\simeq$4.85 Gyr.

Like the Sun, α Cen A shows evidence of chromospheric emission in the optical and ultraviolet spectral regions [2] [8] and should therefore also have atmospheric regions where the temperature gradient turns from negative to positive.

The rise in temperature beyond the "minimum temperature" region is caused by non-radiative energy being deposited, which leads to the heating of the higher atmospheric levels. The minimum temperature of the solar atmosphere can be measured directly in the far-infrared (FIR) [4], [1]. In the wavelength region $\sim$50 – 350 μm, the atmosphere becomes optically thick owing to the dominating H^- free-free opacity ($\propto \lambda^2$; [6], [3]) and, consequently, radiates at lower temperatures than the layers beneath (the photosphere in the visible, where $\tau(0.5\mu\mathrm{m}) > 1$).

Fig. 1 shows the temperature profile of the quiet solar chromosphere around the temperature minimum. The information provided by the continuum in the FIR is crucial to model that region. By analogy, this phenomenon can also be expected on α Cen A. We obtained such data with the ESA *Herschel* Space Observatory [12] in the FIR and complementary ones with the ground-based APEX submillimetre (submm) telescope. These facilities allow photometric imaging observations with high sensitivity.

2 The observations

PACS scan maps [13] of α Cen were obtained in 2011 for the DUNES programme [5] at 100 and 160 μm. In addition, PACS 70 and 160 μm and SPIRE 250, 350 and 500 μm [7] data obtained as part of the Hi-GAL programme [10] were also analysed. The LABOCA [14] observations were made during two runs, in 2007 and 2009. The data associated with the programmes 380.C-3044(A) and 384.C-1025(A) were retrieved from the ESO archive.

3 Results

In Fig. 2 we can see the spectral energy distribution for α Cen A from the optical to the submm range. The observed FIR fluxes seem somewhat lower than in the model but appear to turn upward in the submm/mm bands. The 1D Gaia/PHOENIX model describes atmospheres in local thermodynamical equilibrium and does not account for any temperature inversion. In the FIR, the emission from the solar chromosphere exhibits a minimum in brightness temperature around 150 μm [1], with a ratio $T_{\rm min}/T_{\rm eff} = 0.73 - 0.77$.

Therefore, in view of the similar behaviour of the α Cen A observations as compared with the solar ones, it is interesting to do a similar exercise, namely, the computation of the brightness temperature derived from the observed fluxes at each wavelength. The underlying assumption is that the continuum at a particular wavelength λ originates in a region such as $\tau_\lambda \sim 1$: The optical depth in the optical is unity ($\tau_{0.5} \sim 1.0$), but the temperature minimum is found in regions higher up, where $\tau_{\rm FIR} \sim 1$ but $\tau_{0.5} \ll 1$. Details on the estimation of the

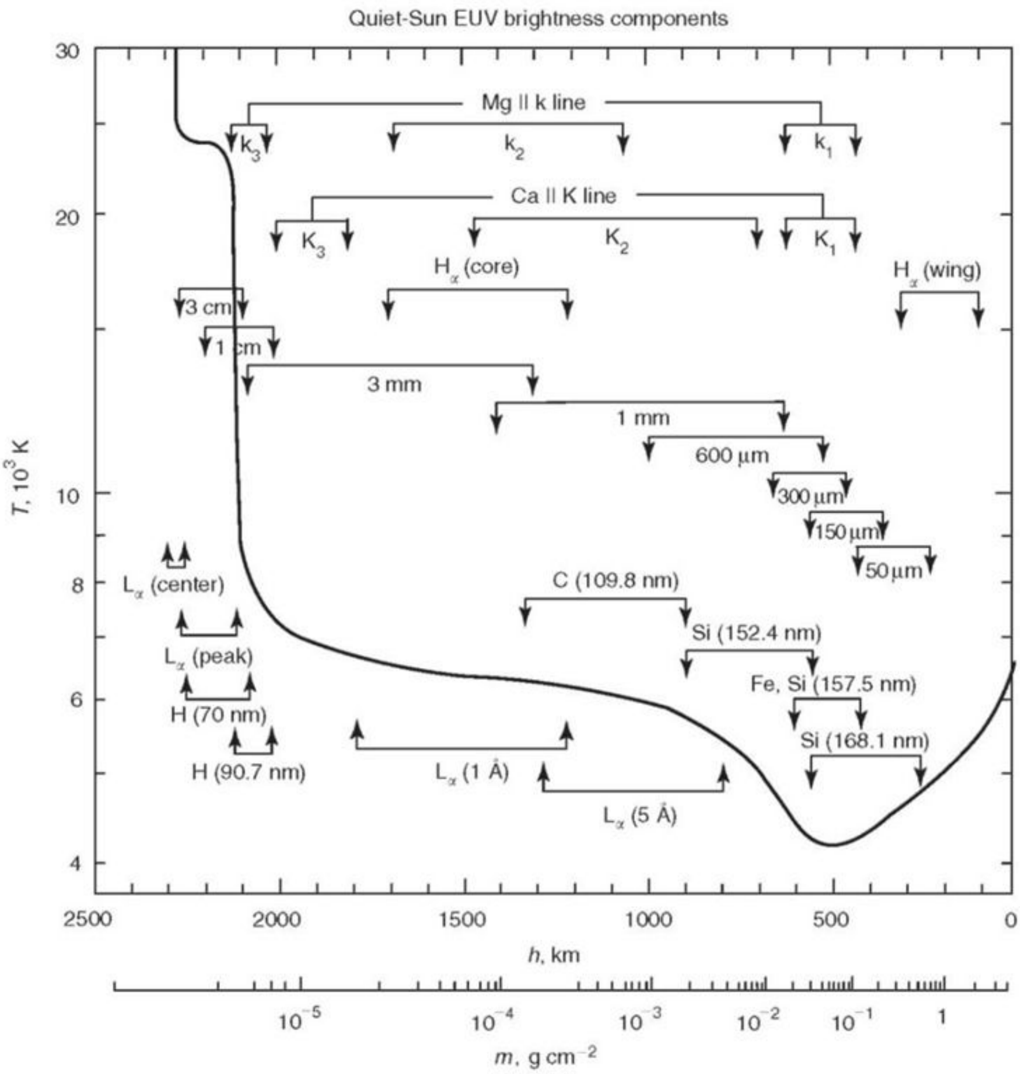

Figure 1: Model temperature distribution for the average Quiet Sun. It can be seen that appart from some UV Si, Fe and Mg, and optical Ca features, the temperature minimum region can be mapped with observations in the FIR continuum from 50 to 600 μm. Figure taken from [11].

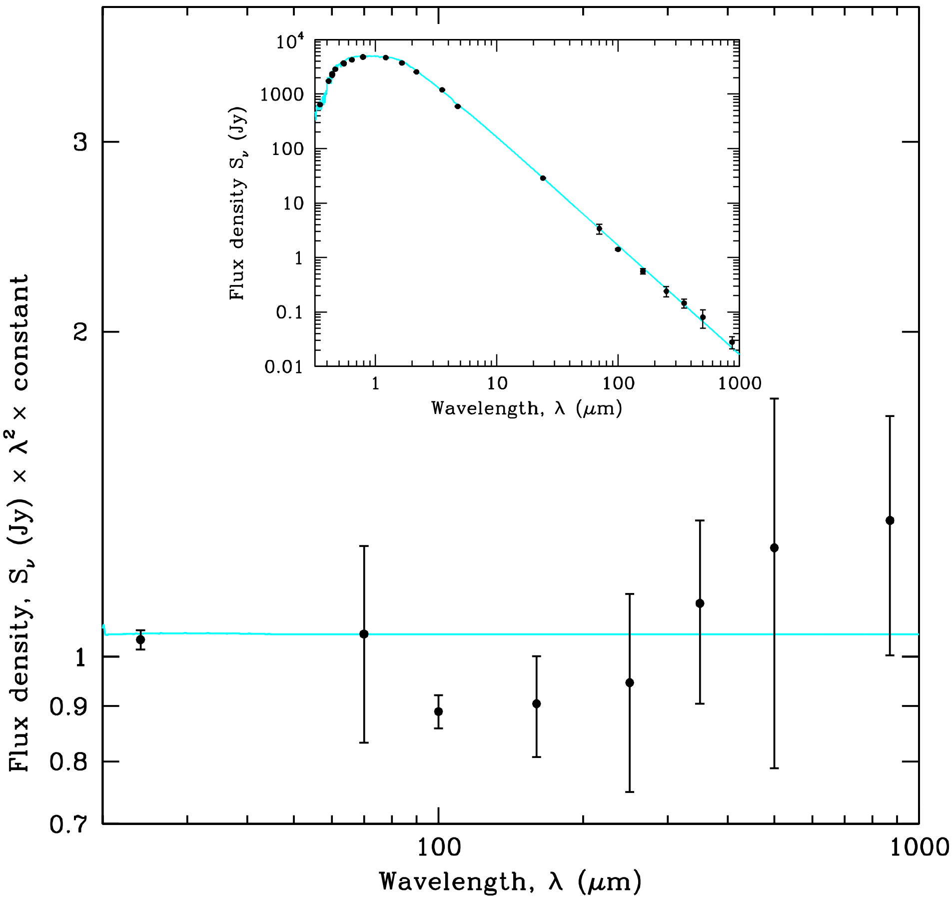

Figure 2: In the inset, the spectral energy distribution of α Cen A from the optical to the submillimetre range with a photospheric Gaia/PHOENIX model specifically computed for this star. Occupying the whole frame, the Rayleigh-Jeans extrapolation of the photospheric model from 45 μm multiplied by λ^2 and an arbitrary constant; and the *Spitzer* MIPS 24; *Herschel* PACS 70, 100, 160; SPIRE 250, 350, 500 and LABOCA 870 μm plotted at the same scale.

brightness temperature can be found in [9].

Table 1: Photometry and brightness temperatures for α Cen A

λ_{eff} (μm)	$S(\nu)$ (Jy)	$T_{\text{B}}(\nu)$ (K)	Band
24	28.53±0.58	4736±91	MIPS
70	3.35±0.03	4540±37	PACS
100	1.41±0.05	3909±135	PACS
160	0.56±0.06	3920±394	PACS
250	0.24±0.05	4084±845	SPIRE
350	0.145±0.028	4822±927	SPIRE
500	0.08±0.03	5421±2018	SPIRE
870	0.028±0.007	5738±1432	LABOCA

In Table 1 we show the observed fluxes $S(\nu)$ and the brightness temperatures $T_{\text{B}}(\nu)$ corresponding to the MIPS 24; PACS 70, 100, 160; SPIRE 250, 350, 500 and APEX/LABOCA 870 μm observations of α Cen A. The difference between the brightness temperature in the region $100 - 160$ μm and that derived from the purely photospheric model is about -500 K. For α Cen A, the ratio $T_{\text{min}}/T_{\text{eff}}$ is 0.67±0.06 around 160 μm.

4 Conclusions

We successfully observed the far infrared energy distribution of the nearby solar twin α Cen A with the PACS and SPIRE instruments on board *Herschel* and with APEX/LABOCA on the ground. The observed radiation temperatures are lower than those expected from extensions of LTE photospheric models. Near 160 μm the minimum temperature in the atmosphere of this star is $T_{\text{min}}/T_{\text{eff}} = 0.67 \pm 0.06$. At 870 μm the emission appears to originate in regions with higher temperatures.

Acknowledgments

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