ALMA Tomography of Stellar Chromospheres

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Extended Abstract

Aiming at the ultimate understanding of the non-radiative heating of stellar chromospheres and coronae we use the submm/mm interferometer ALMA (Atacama Large Millimeter Array) to frequency-map the spectral energy of stars. This procedure can be shown to be analogous to scanning these atmospheric layers in geometric space. Using theoretical models, the physical structure of these regions that are out of thermodynamic equilibrium can be retrieved. The results can be compared to various predictions by theories of the heating.

The unprecedented high sensitivity of ALMA makes the observation of stars in the submm/mm finally feasible and first detections are now about of being reported [1, and references therein]. Observed stellar flux densities largely exceed the values expected on the basis of the photosphere (unit optical depth surface in the visible), i.e. originate in regions of higher temperature. Going along in frequency, the associated brightness temperature $T_B(\nu)$ measures that actual physical temperature as long as the emission is optically thick, i.e.

if $\tau_\nu >> 1$, the flux density S_ν maps the temperature as function of chromospheric height, i.e. $T_B(\nu) = T(h)$

$$T_B(\nu) = \frac{2\pi\hbar\nu}{k}\left[\ln\left(\frac{4\pi^2 R_{star}^2 (1.0 + h/R_{star})^2 \hbar\nu^3}{D^3 c^2 S_\nu} + 1\right)\right]^{-1}$$

else if optically thin, $\tau_\nu << 1$, S_ν measures the chromospheric density, n(H), since

$$S_\nu \propto \frac{EM}{T} = T^{-1}\int n_e n_i \, dh$$

In other words, submm/mm data provide directly *observed* structures of stellar chromospheres. Differences with respect to earlier results obtained more indirectly in the UV and optical have been noticed. ALMA data of both the Sun and stars will eventually help elucidate the cause(s) of the temperature rise up to several million of degrees in the coronae of stars (Fig. 1).

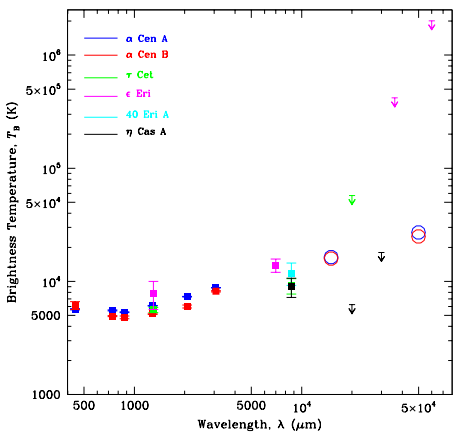

Figure 1. Brightness temperatures for six solar-type stars at wavelengths from 0.5mm to 6 cm. Detections were obtained below 1 cm and merely upper limits above that wavelength. The color coding and stellar identifications are given in the upper left corner of the figure. The open circles denote estimates of future ATCA detections of α CenAB in 12 hours at 20 and 6 GHz, respectively. References to the data can be found in [1].

References

1. R. Liseau, V. De la Luz, E. O'Gorman, E. Bertone, M. Chavez and F. Tapia, "ALMA's view of the nearest neighbors to the Sun", *Astronomy & Astrophysics*, **594**, October 2016, A109, 9 pp., doi: 10.1051/0004-6361/201629135