The Solar Transition Region from UV and microwave observations

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Abstract. The quiet sun chromosphere-corona transition region is analyzed by comparing the ultraviolet line intensities (observed by the SOHO satellite) with the radio emission in the microwave range. Results from the two wavelength ranges seem to be in strong disagreement when standard techniques are applied to UV data. A more careful analysis of the line intensities done separately in the network and in the cell decreases the disagreement, but it does not remove it. It is finally shown that the most important reason of disagreement comes from the lowest portion of the transition region, at $\log T < 4.5$, where the plasma parameters derived from the UV lines (no more optically thin) are very uncertain. The radio emission puts therefore important constraints on the physical parameters of this portion of the solar atmosphere.

Key words. Solar Transition Region– Solar UV lines–Solar microwaves

1. Introduction

The chromosphere-corona transition region (TR) can be investigated by analysing the intensity of ultraviolet (UV and EUV) lines and the radio emission, mostly in the microwave range ($1 \leq \lambda \leq 21$ cm). The output of radioastronomical observations is usually given in terms of brightness temperatures, $T_b(\lambda)$, related to the emitted intensity, $I_\lambda$, by the relation: $T_b(\lambda) = \lambda^2 I_\lambda / 2k$ where $k$ is the Boltzman constant.

Both the intensity of UV lines and the radio brightness temperature depend on the electron temperature and, if the temperature gradient is not zero, on the Differential Emission Measure (DEM) defined as:

$$DEM(T) = N_e^2 dh / dT$$

We would therefore expect to reproduce the observed $T_b$ by using the $DEM$ curve derived from UV line intensities into the radio transfer equation.

2. Comparison between observed and computed $T_b$

In Fig.1a) we have plotted the quiet Sun observations performed by Zirin, Baumert...
Fig. 1. (a) Microwave spectrum observed by Zirin et al. (points with error bars) and
by Borovick et al. (diamods): the full line represents the two-temperature fit proposed by
Zirin et al. and the dashed line the computed $T_b$ obtained using the TR DEM derived
from EUV line intensities. (b) Differences between observed and computed Zirin et al. $T_b$,
 fitting with a 3rd order polinomial (dotted line). The dotted line in panel (a) is obtained
adding this contribution to a two-temperature fit (see text).

and Hurford (1991) at Owens Valley and
by Borovik, Kurbanov and Makarov (1992),
at the RATAN 600 radio telescope: the
two sets of observations show a very good
agreement. Zirin et al. (1991) have shown
that the microwave spectrum is very well
accounted for by a step model, consisting
of a chromosphere at $T_{\text{chr}} \approx 11000 K$
and a corona, assumed in hydrostatic equilib-
rium, at $T_c \approx 1 \times 10^6 K$. No transition
region is considered in this model. Results
from this model are represented by the full
line in Fig.1a). However, a careful analy-
sis of the differences between the Zirin et
al. (1991) observed and computed $T_b$ (Fig
1b) shows that they are not normally dis-
tributed around zero, but they are all pos-
itive (and in some cases larger than the
error bars) up to $\nu \approx 10$ GHz and all
negative and normally distributed around
$\sim -700 K$, above this frequency.

The excess of the observed $T_b$, (dotted line
in Fig 1b) is interpreted as due to the ne-
glected TR contribution. Adding this con-
tribution to the Zirin et al. (1991) fit in
which $T_{\text{chr}}$ is replaced by $T_{\text{chr}} - 700 K$
we obtain the dotted line in Figure 1a), which
fits much better the observations. It must
be pointed out that the TR contribution is
very small, reaching, at maximum, 10 % of
the observed $T_b$ at $\nu = 5$ GHz.

The computed $T_b$, obtained using the DEM
(T) derived from the average quiet sun line
intensities, observed by the CDS-NIS in-
strument, is much higher than the obser-
vations at all temperatures (dashed line in
Fig.1a)

The aim of this paper is to understand this
discrepancy. The only assumption made
in the calculation of the radio bright-
ness temperature, is that the electrons fol-
low a Maxwellian distribution. If this is
not the case, the bremsstrahlung emis-
sivity and absorption coefficient can be differ-
ent (Chiuderi and Chiuderi Drago, 2003).

The derivation of the DEM from the EUV
line intensities presents more uncertainties
due to the need of large amounts of atomic
data, element abundances and ion fractions. Other possible reasons for the disagreement rise 1) from the fact that most UV lines are not optically thin at low temperatures, while the \( DEM \) determination relies on the optically thin assumption, and 2) from the extension of the \( DEM \) maximum temperature to \( 10^8 \) K. This latter assumption is in clear conflict with the presence of an isothermal corona at \( T \sim 10^6 \) and has been recognized as the main reason of disagreement between EUV and metric observations of a Coronal Hole (Chiuderi Drago et al., 1999).

Finally, the comparison between EUV and microwave observations was done assuming a homogeneous model of the solar atmosphere, while the network and cell structures are very pronounced in the TR. It is possible that on the average quiet sun emission, cell and network play a different role in the two frequency ranges.

3. An inhomogeneous model

We have measured the EUV line intensities in the cells and in the network from CDS-NIS to derive the corresponding \( DEM \). This calculation has been also performed using the cell and network line intensities measured by Curdt et al. (2001) on SUMER. For all sets of data the maximum temperature for the \( DEM \) derivation was set at \( T_c = 1.2 \times 10^6 \) K, and a corona in hydrostatic equilibrium at the same temperature, with density \( N_e(0) = 2 \times 10^8 \) cm\(^{-3}\) was taken into account. The resulting \( T_b(\text{cell}) \) agrees with the observations at frequencies lower than \( \nu \sim 2 GHz \), but, above this frequency, it is always overestimated.

A detailed analysis of the radio transfer equation indicates that this disagreement is generated in the lowest portion of the TR where, at \( T \sim 2 \times 10^4 \) K, the optical depth is \( \tau \gg 1 \) at all frequencies. This temperature becomes therefore the limiting value of the computed \( T_b \) at high frequencies, contrarily to the observed value of \( \sim 1 \times 10^4 \) K. The major cause of discrepancy between radio and UV observations is therefore related to the very high \( DEM \) values at low TR temperatures where most of lines are not optically thin and the \( DEM \) values are rather uncertain. A confirmation of this uncertainty comes from Fig.2 where we have plotted the \( DEM \) values derived from the cell line intensities observed by SUMER and CDS: the curves show a very good agreement above \( log T \sim 4.7 \), but they strongly disagree below this temperature. In the same figure the \( DEM \) derived from the cell model of Vernazza, Avrett and Loeser (1981) (hereafter VAL) in the temperature range \( 4.0 \leq log T \leq 4.3 \), are also shown. The strong disagreement among the different \( DEM \) displayed in Fig.2 indicates severe problems in the DEM diagnostics at low temperatures, and shows that the microwave observations can provide very important contraints at these temperatures.

Microwave observations indicate that only the calculations performed assuming the dotted line in Fig 2 (VAL model below \( log T = 4.3 \), average SUMER and CDS results above \( log T \sim 4.6 \)), supplies an acceptable fit of the observations along the whole considered radio spectrum as shown.

![Fig. 2. Differential emission measure \( DEM \) as derived from CDS (full line) and SUMER (dashed) line intensities measured in the cells. Diamonds are the \( DEM \) derived from the VAL model B (average cell center). The dotted line represents the \( DEM \) used to derive the \( T_b \) displayed by the dotted line in Fig 3.](image-url)
Cell center Radio Brightness Temperature obtained from the three DEM vs. T curves shown in Fig 2, plotted with the same linestyle. The coronal contribution has been added to each of them.

in Fig. 3. All calculations presented so far are referred to the cell models. Since the computed $T_b$, although within the error bars, are always closer to the upper limit of the observations, it appears that any contribution from the network added to the it will make the computed $T_b$ in excess to the observations. The only way to decrease the computed $T_b$, keeping unchanged the TR model, is to decrease the coronal contribution, which, in the hydrostatic equilibrium assumption, scales as $N_e^2T^{1/2}$. Decreasing $N_e(0)$ to $1 \times 10^8$ cm$^{-3}$, the maximum network contribution which can be added to the cell $T_b$, maintaining the computed curve within the error bars, is 10%. A further decrease of $N_e$ will make the coronal contribution negligible with respect to that of the TR so that it will not influence the cell/network percentage. It has been recently shown by Chiuderi and Chiuderi Drago (2003) that the presence of a 20% of superthermal particles in the electron population can decrease the resulting $T_b$ of $\sim 10\%$ as shown by Fig 4 of this paper.

References
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