The formation of the Mg I 12-micron emission lines

Mats Carlsson[1], Robert J. Rutten[2] and Natalya G. Shchukina[3]

[1] *Institute of Theoretical Astrophysics, Oslo, Norway*
[2] *Sterrekundig Instituut, Utrecht, The Netherlands*
[3] *Main Astronomical Observatory, Kiev, USSR*

The Mg I 12 μm lines

The emission features near 12 μm measured by Brault and Noyes (1983) and identified as Mg I Rydberg lines by Chang and Noyes (1983) supply sensitive diagnostics of solar magnetic fields (Deming *et al.* 1988)—but in order to use them their nature and sphere of formation should be known. Sofar it isn't clear whether they are chromospheric or photospheric, optically thick or thin, LTE or NLTE. We briefly discuss these issues here, using the observational facts that (*i*)–the lines are in the infrared; (*ii*)–the lines consist of narrow central emission spikes and broad absorption wings; (*iii*)–both cores and wings limb-brighten in absolute intensity while the continuum darkens.

LTE or NLTE

LTE formation requires deep formation since the Saha–Boltzmann opacity is much too low higher up in the solar atmosphere. LTE formation also requires the presence of a minimum in the run of temperature with height to explain the profile shape. These points led **??** to postulate from their adoption of LTE that the chromosphere sits much deeper than anyone has ever thought, discarding all other evidence for the location of the temperature minimum, and to disclaim the existence of kilogauss flux concentrations in the photosphere as well. However, the absorption dips map the temperature minimum if LTE holds, so that the lines should display similar intensity minima from center to limb, at increasing separation from line center. This is in obvious conflict with the observed wing brightening which shows immediately that, for LTE opacities, a frequency-dependent total source function is required, thus a two-component source function, thus a NLTE S^l. Zirin and Bopp conclude that "the 12 μm lines can tell us quite a bit if we stare at them long enough" but a mere glance suffices to disprove any LTE scenario.

Chromospheric formation

Formation in the chromosphere requires large NLTE line opacity, appreciably exceeding Saha–Boltzmann populations. This can't be done in deeper layers where collisions are frequent because the infrared photon energies involved in Rydberg *bb* and *bf* transitions are much smaller than the kinetic energies of the ambient particles: only at large height can any NLTE process maintain appreciable departures against collisional thermalization. Such a process (*e.g.,* charge exchange) must then produce enormous Rydberg-level overpopulations to produce sufficient opacity. The emission peak would then have to arise from a hot chromospheric layer which is optically thin at line center conform the limb brightening, whereas the extended absorption wings would then not come from the same layer but arise differently, far deeper. Such a split is unlikely because the wings limb-brighten similarly to the peaks.

Photospheric formation

The alternative is to have near–LTE line opacities but an NLTE line source function, *i.e.,* divergence between the upper and lower level population departures. Lemke and Holweger (1987) have shown that small (5%) departure divergence suffices to produce satisfactory source function departure if it occurs deep enough in the photosphere. By ad-hoc postulation of such departure divergence they were able to fit the observations, both peaks and wings, including the limb brightening.

There are three reasons why such small divergence suffices. First, as pointed out by Lemke and Holweger, the sensitivity of the source function to population departure divergence increases towards the infrared with the importance of induced photo-deexcitation. Second, as pointed out by Goldberg (1983), the profile of the line extinction coefficient becomes more spiked towards the infrared. Third, the outward decreasing slope of temperature against height translates in the infrared (where the Planck function temperature sensitivity is small) into a flat infrared line source function already for small NLTE departure, producing extended shallow absorption wings as observed.

However, Lemke and Holweger were unable to explain how such photospheric population divergence might arise. Their ad-hoc divergence remains far below the domain of population inversion (this wasn't grasped by Zirin and Bopp who erroneously equate population divergence with "laser action"), but it exceeds what NLTE photon processes can typically produce.

Collisional NLTE: departure diffusion

We are currently modeling the solar Mg I spectrum including large numbers of Rydberg levels and lines using Carlsson's (1986) implementation of the method of Scharmer and Carlsson (1985) for a standard plane-parallel radiative-equilibrium model atmosphere without chromosphere.

Our preliminary results confirm the ad-hoc model of Lemke and Holweger and identify the NLTE mechanism. The emission is not due to selective properties of specific levels or to fortuitous pumping coincidences but is a natural consequence of the replenishing of NLTE population losses in a minority species from the population reservoir in the next higher ionization stage. We find that the driving population deficits are due to photon losses in lines with 6–7 eV excitation energy while stronger lines, ultraviolet overionization from low levels, ultraviolet autoionization resonances of higher levels and dielectronic recombination into Rydberg levels are less important. The replenishing from the Mg II reservoir occurs primarily through *collisional departure diffusion* along a close-stepped ladder of high-lying Rydberg states. Paradoxically, the high-n Mg I lines therefore display NLTE formation due to their domination by collisional processes.

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