Ellerman bombs - physical parameters derived from high-resolution multi-line spectroscopic observations

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ABSTRACT

Observations of Ellerman bombs (EBs) show them as small brightenings, which are well observed in hydrogen H-alpha line wings. H-alpha line profiles of EBs exhibit enhanced emission at a distance of 0.8 ang. on the both sides of the line core. These increases of emission can be visible in the optical spectra even up to a few angstroms from the line core and were reported in the past as a “moustaches” phenomenon (Bruzek 1968). EBs can be also observed in other chromospheric lines (e.g. in Ca II 8542 ang.) and in UV as a bright points often located close to sunspots within active regions. EBs are probably a manifestation of small reconnection processes occurred in the solar lower atmosphere.

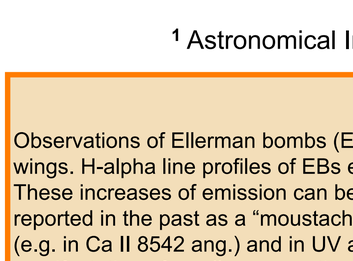
We used high-resolution spectroscopic observations of EBs to derive the model of the active solar atmosphere in these structures. In 2007 and 2011 some Ellerman bombs were observed with high-resolution Dutch Open Telescope (DOT, La Palma) and spectroscopically with Dunn Solar Telescope (DST) located in National Solar Observatory (Sacramento Peak, USA). DST was coupled with Interferometric BIdimensional Spectrometer (IBIS) and we obtained spectral line profiles of EBs in H-alpha, Ca II and Na I lines.

The obtained spectral images and line profiles were compared with the grid of the theoretical line profiles computed with NLTE radiative transfer code for different atmospheric models. By modifying the solar atmospheric model we found the best fit between observations and theoretical spectrum. In this way we obtained the most probable semiempirical model of the active atmosphere in Ellerman bombs.
During the talk we will also discuss the limitations of our modelling and plans for their further development.

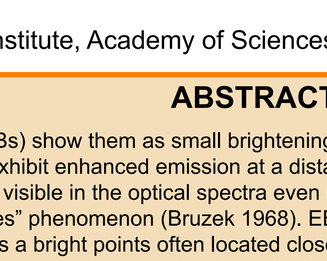
1. ELLERMAN BOMBS - OVERVIEW

Ellerman 1917 – hydrogen bombs → Ellerman Bombs (EBs) → moustaches (observations from 1909)

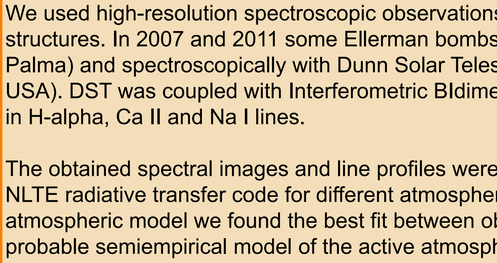
- bright compact structures, size 1’’ – 1’’.5
- enhanced emission in Hα wings, but not in the line centre
- life-time – minutes
- location: around sunspots, areas of new emerging fluxes, magnetic dips
- recurrent events possible



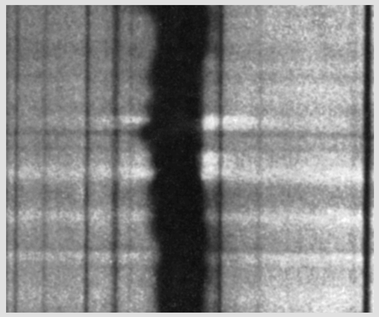
Georgoulis et al. 2002



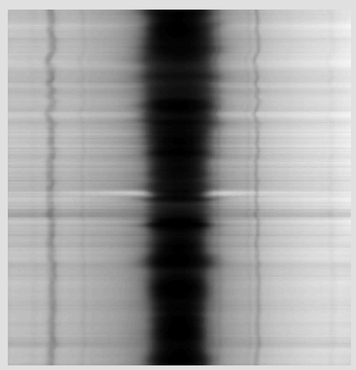
Ellerman bombs (EBs) are also observed in UV continuum, e.g. at 160 nm, as Bright Points



Possible model of Ellerman bomb formation (Matsumoto et al. 2008)



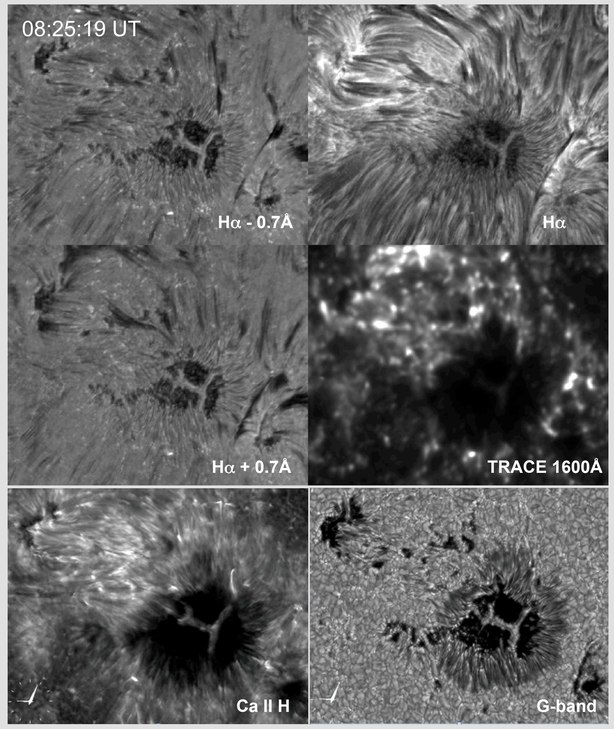
Hα moustache spectra of Ellerman bombs (above: Mount Wilson Solar Observatory, below: THEMIS, Observatoire de Paris, (courtesy: B. Schmieder)



Appearance of EBs in the Hα line wings and in UV continuum suggests that EBs are probably located in lower chromosphere

2. DUTCH OPEN TELESCOPE (DOT) OBSERVATIONS OF ELLERMAN BOMBS

DOT and TRACE observations: time sequence: **07-Jun-2006, 08:20 – 09:30 UT (no line profiles)**
Hα, Hα-0.7Å, Hα+0.7Å, Ca II H, Ca II H-2.3Å, G-band, TRACE 1600Å



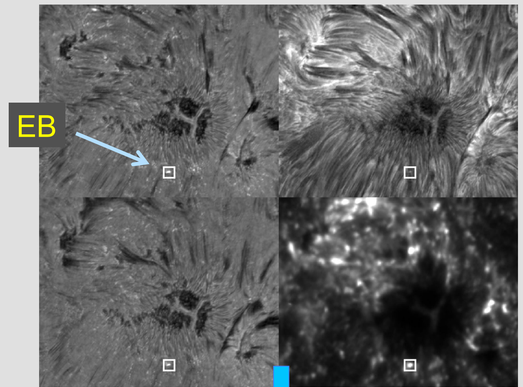
DOT and TRACE observations: **08:20 – 09:30 UT**

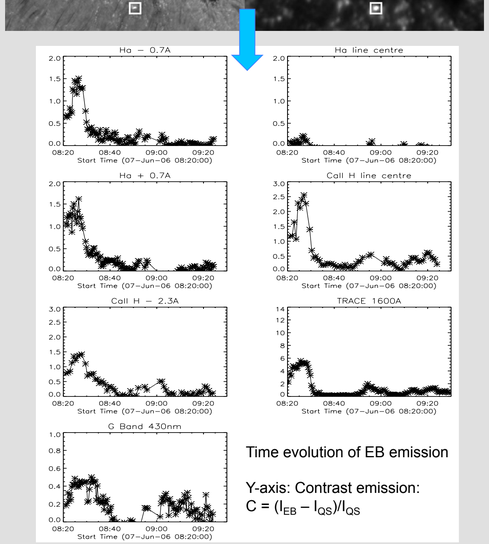
- ✓ AR 10892, FOV: 80’’ × 65’’
- ✓ Original scale: 0.071’’/pix. for DOT, then degraded
- ✓ TRACE: 146 images, mean cadence = 29s, coaligned
- ✓ DOT: 134 images, , mean cadence = 27s, coaligned

The emission of Ellerman bombs is well visible in the wings of Hα line but almost not visible in the line centre. They are also bright in Ca II H line and in UV at. 160 nm

AR 10892

We found several Ellerman bombs in the FOV and we analysed their emission in all spectral windows:



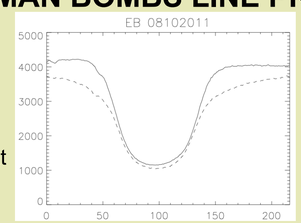


Time evolution of EB emission

Y-axis: Contrast emission: $C = (I_{EB} - I_{QS})/I_{QS}$

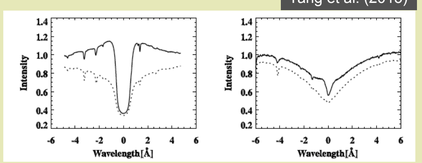
3. ELLERMAN BOMBS LINE PROFILES

There are not many observations of Ellerman bombs line profiles. Usually, the profiles show absorption in line core and enhanced line wings, with the maximum at about 1Å from line centre. Sometimes line profiles are not symmetrical what suggests the plasma flows in EBs



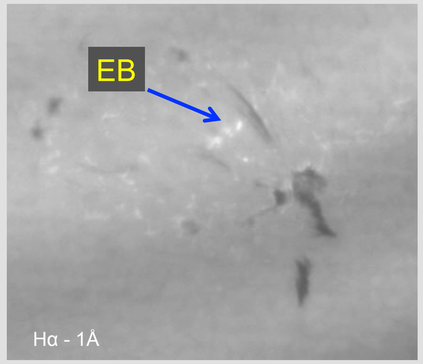
(THEMIS, courtesy: B. Schmieder)

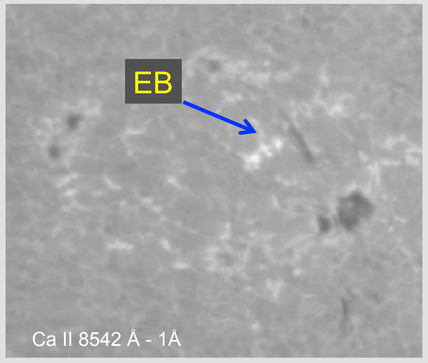
Yang et al. (2013)

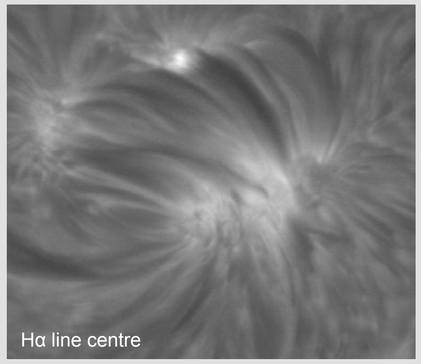


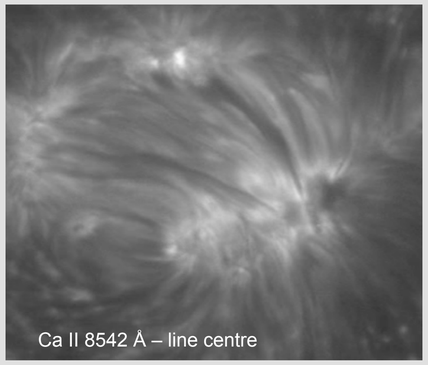
Hα Ca II 8542 Å

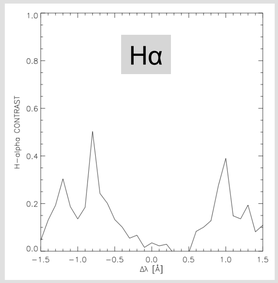
4. SPECTROSCOPIC OBSERVATIONS OF ELLERMAN BOMBS WITH DST/IBIS
(Dunn Solar Telescope / Interferometric BIdimensional Spectrometer

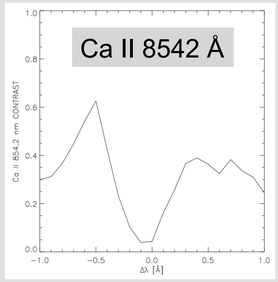












From IBIS observations we could reconstruct contrast profiles of EB in its maximum brightness

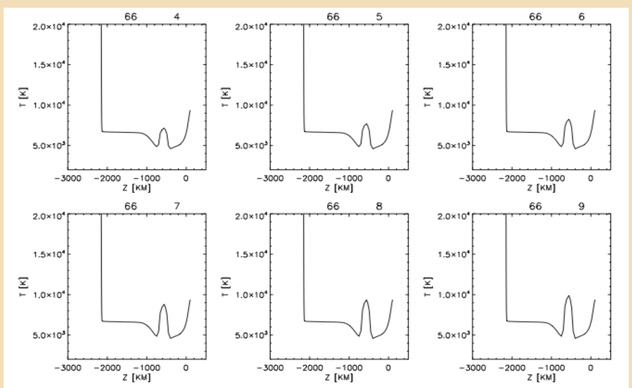
Data: August 7, 2011, AR 11267

5. NLTE MODELLING OF ELLERMAN BOMBS

How do we find the model?

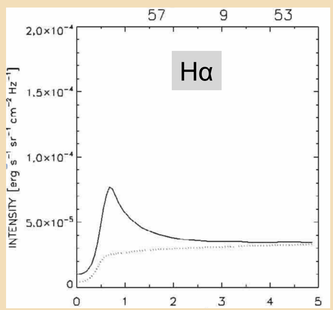
We used NLTE codes for calcultion of synthetic Hα, Ca II spectrum (P. Heinzel) (1D geometry, MALI approach, input model: C7 (Avrett, Loeser 2008)

First, we have modified the C7 semiempirical model of the quiet-Sun by adding **„hot-spot"** structure to simulate the disturbance of the solar atmosphere caused by Ellerman bomb **(Figure below)**. We constructed the grid of 243 models, which differs by the position and strength of the „hot-spot" feature.

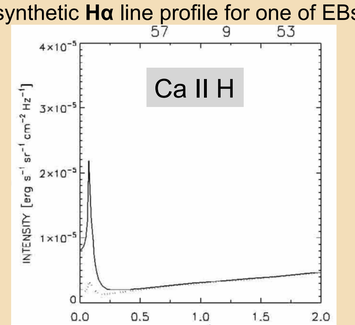


Example of temperature distribution for some "hot-spot" models

For all these models we could calculate the synthetic Hα and Ca II line profiles **(Figures in the right)**



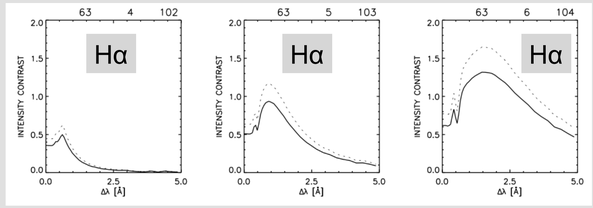
Example of synthetic **Hα** line profile for one of EBs model

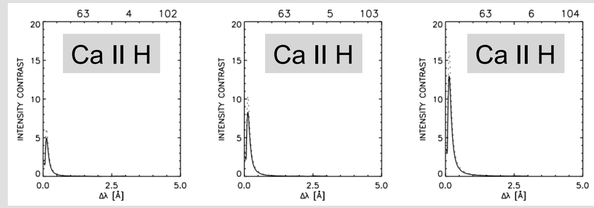


Example of synthetic **Ca II H** line profile for one of EBs model

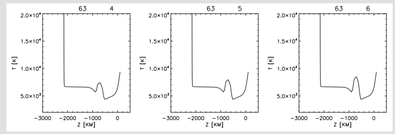
6. COMPARISON OF THE THEORETICAL LINE PROFILES WITH OBSERVATIONS

In order to compare the theoretical profiles with observations and to avoid problems with absolute calibration, we used contrast theoretical profiles $C = (I_{EB} - I_{QS})/I_{QS}$.



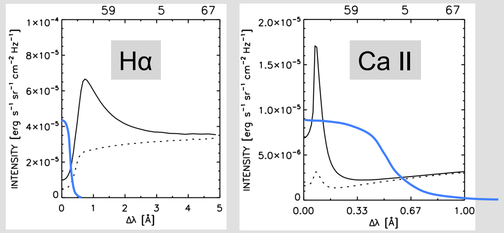


Examples of the contrast profiles **(Figure above)** for 3 different semiempirical models with „hot-spot" feature **(Figure below).**

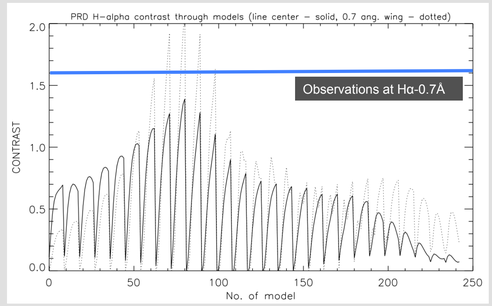


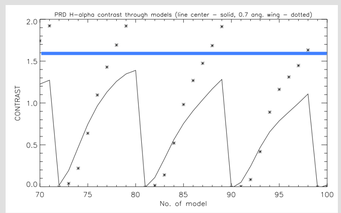
Pass-band parameters of DOT filters:
Hα, Hα-0.7Å, Hα+0.7Å: FWHM = 0.25 Å,
Ca II H, Ca II H-2.3Å: FWHM = 1.35 Å

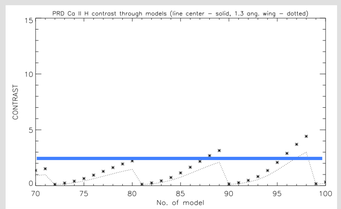
We have the contrast for the theoretical line profile, but for DOT data we have only contrast in images obtained through filters. How to compare? **Apply filter pass-band curves to the theoretical line profiles** (and then calculate the contrast for wavelengths corresponding to filters positions)

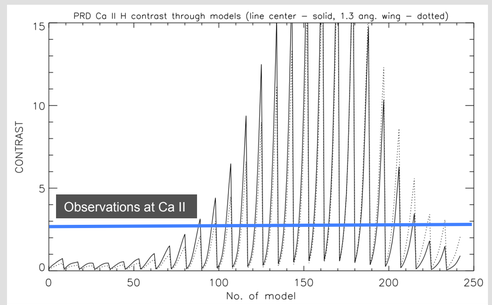


And finally we obtain the contrast at filters position for all 243 „hot-spot" models of the grid:

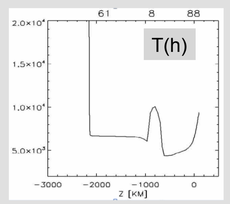


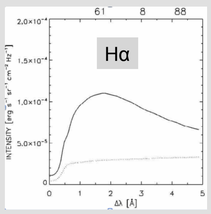


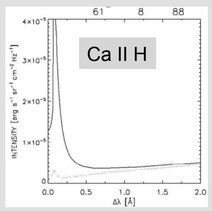




Detailed analysis **(Figure in the left)** allows us to determine one of the „hot-spot" model, which best fits the observations of Ellerman bombs in the Hα line wing and Ca II H line core. The temperature distribution of this model and the emergent line profiles are shown below







7. CONCLUSIONS

- For the first time relation between optical Hα and Ca II emission observed in EBs was used to construct the semiempirical model of Ellerman bomb;
- Obtained model of EBs atmosphere is characterized by a temperature peak (hot-spot) around the temperature minimum;
- At least two spectral lines are necessary to find a unique model of EBs
- Effects of particle beams, microturbulence, 2D/3D geometry and magnetic field should be included in the modelling;