ELLERMAN BOMBS

Rob Rutten

Gregal Vissers & Luc Rouppe van der Voort

Institute of Theoretical Astrophysics, Oslo

- EBs are brief bright Hα moustaches in complex emerging active regions
- pseudo-EBs are just magnetic concentrations
- EBs mark strong-field reconnection in the photosphere
- EBs can show hot to very hot photospheric heating in IRIS spectra
- EBs probably mark long-pull-up serpentine U-loop emergence
- EBs observed in SDO/AIA 1700 Å can serve as photospheric reconnection locator
- EB reconnection topography may serve as constraint in NLFFF modeling

ELLERMAN BOMBS

SOLAR HYDROGEN "BOMBS"

By FERDINAND ELLERMAN

Visual and photographic observations of a solar phenomenon which had previously escaped our attention have been carried on at this observatory during the past two years.

On September 21, 1913, while the writer was observing the Hα line for reversals and distortions in an active spot-group, there suddenly appeared a very brilliant and very narrow band extending four or five angstroms on either side of the line, but not crossing it. In a couple of minutes it faded away and was not seen again. A month later, on October 21, more observations were recorded and a spectrogram was secured.

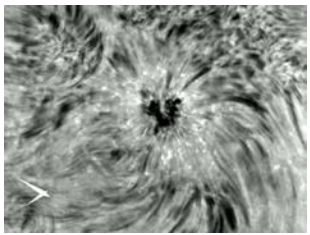
On the first occasion the appearance was so extraordinary that it seemed hardly real; after the second observation, however, the existence of such phenomena as part of the solar activity seemed established, and a search has been made for them whenever conditions of seeing and other work have permitted.

There are two conditions essential for observation—good seeing and a large solar image—as the area of the phenomenon, even with the 16-inch image of the sun at the 150-foot tower telescope, is so small that only with difficulty is the point of disturbance kept on the slit.

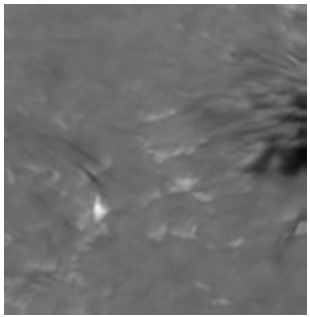
The appearance of the phenomenon indicates something in the nature of an explosion, in which hydrogen seems to be the only element playing a part. The duration is only a few minutes—from one to three on the average, and from five to ten minutes rarely. This sudden performance suggested the name of hydrogen "bomb," which we have adopted to designate it.

In the *Astrophysical Journal*, 38, 78, 1913, Dr. Walter M. Mitchell gives an account of solar observations made at Haverford College Observatory, together with a drawing which illustrates the appearance of Hα in the spectrum of a "bomb," and from his

- Mount Wilson: solar hydrogen bombs
  Ellerman *1917ApJ....46..298E*
  - sudden brightenings in Hα wings
  - not in line core, only in Balmer and Ca II lines
  - between spots in complex emerging active regions



- DOT: pseudo Ellerman bombs
  Rutten et al. *2013JPhCS.440a2007R*
  - magnetic concentrations in sunspot moat
  - Spruit hole radiation plus small collisional damping
  - blue-wing brightening from downflows



- SST: true Ellerman bombs
  Watanabe et al. *2011ApJ...736...71W*
  - photospheric jets in rapid succession along network
  - shielded in Hα core by overlying fibrils
  - photospheric strong-field reconnection?

ELLERMAN BOMB FADS AND FALLACIES

Rutten et al. 2013JPhCS.440a2007R (125 references)

fallacies

- *EB moustaches*
  - appear in neutral-metal lines
  - appear in network
- *EB Hα profile*
  - dark core = bomb ingredient
  - brighter blue wing = upflow
- *EB height*
  - Hα = chromosphere
  - chromospheric reconnection
- *EB as flare*
  - downward proton beams
  - impact polarization

fads

- *emergence pattern*
  - serpentine Parker instability
  - bald patches
- *anemone jets*
  - downflows and upflows
  - surges
- *cartoon modeling*

ELLERMAN BOMB SST/CRISP OBSERVATIONS 2011–05–07

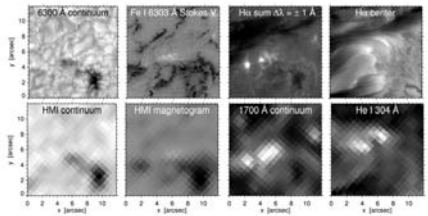
Vissers et al. *2013ApJ...774...32V*

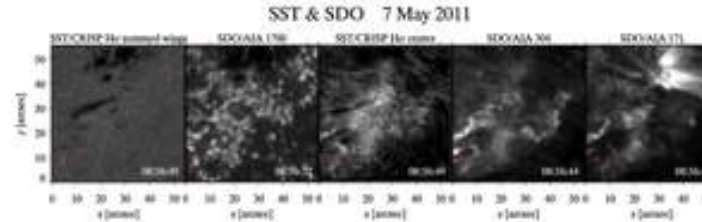
Hα $\Delta\lambda$ = -1.0, 0.0, 1.0 Å

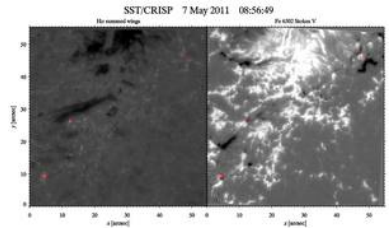
Fe I 6302 Å full Stokes 25 wavelengths

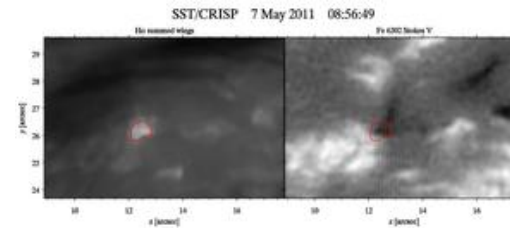
[Ca II 8542 Å full Stokes 25 wavelengths]

variable seeing









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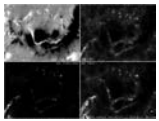

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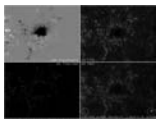

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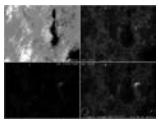

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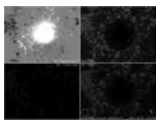

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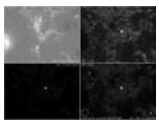

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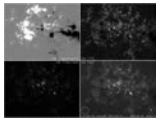
2014 OBSERVATIONAL ELLERMAN BOMB PAPERS



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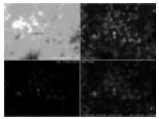
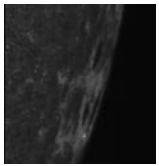


- *Peter et al.* 2014Sci...346C.315P — *IRIS bombs*
  "[the photosphere] hosts pockets of hot plasma transiently heated to almost 100,000 K"



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  "there has been a limited investigation of how these events appear at the limb, specifically, whether they manifest as vertical extensions away from the disc"

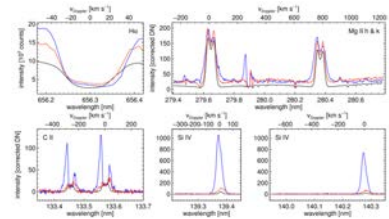
  but note:

  Watanabe et al. 2011ApJ...736...71W — near-limb tall flame morphology
  J.W. Harvey 1963Obs....83...37H — height of an off-limb EB

  "Dear Rob – My first real paper was on Ellerman bombs 50 years ago so I like them too!"

SIMULTANEOUS SST AND IRIS OBSERVATIONS

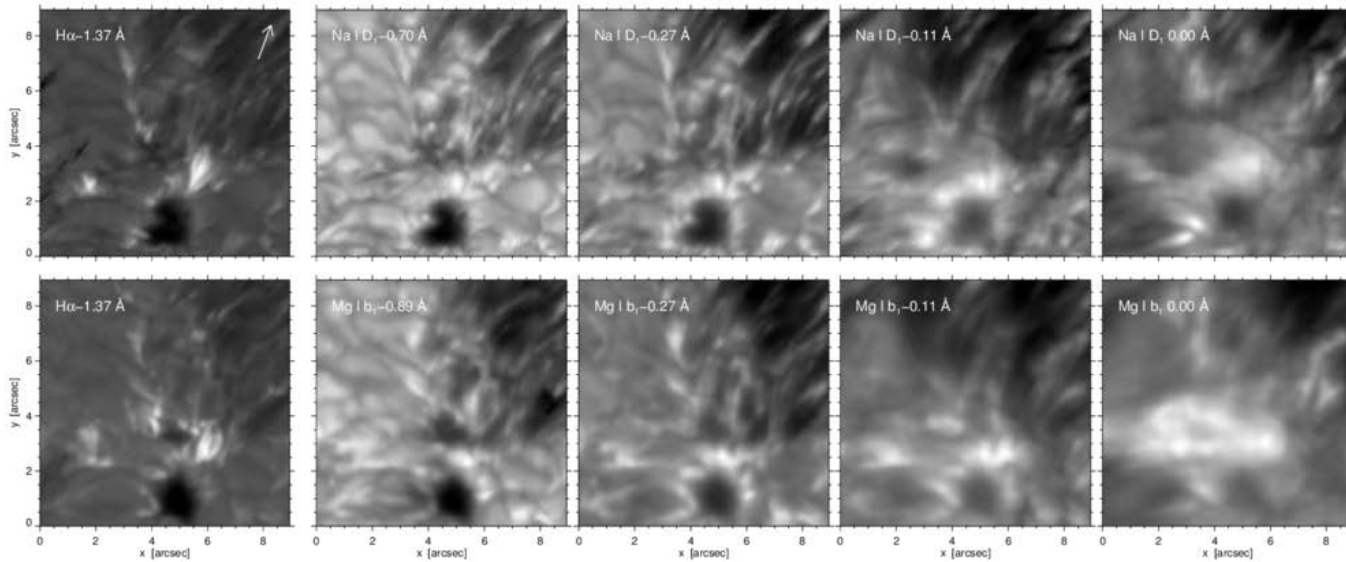
Vissers et al. in preparation



- *Standard (?) = nice flame in Hα, bonafide EB in SDO*
  - cores Hα, Mg II h & k: overlying fibrils (seen in CRISP movie)
  - h & k wings, Mg II triplet, C II Si IV: sample “unveiled” EB underneath
  - EB thin to near-thick in Si IV, thick in C II, Mg II triplet
  - EB bright in all (ignore cores Hα, Mg IIh & k)
  - EB much brighter in upper part
  - pronounced Mg II triplet likely recombination cascade
  - clean thermally broadened and Doppler-shifted profiles
  - downflow in lower part, upflow in hotter upper part (“bi-directional jet”)
- *Abnormal (?) Less tall EBs? Mushroom clouds? FAFs?*
  - SDO 1700 pseudo-EBs: confused IRIS brightenings
  - bonafide EB near flame onset: IRIS bomb signature?
  - small flaring arch filament (FAF): similar signature

ELLERMAN BOMB AFTERMATH: MUSHROOM CLOUD?

SST/CRISP Luc Rouppe van der Voort, July 4 2013
variable seeing: snapshots only
scans through Na I D_1 and Mg I b_1 (7 minutes later) plus Hα



- Ellerman(1917): no bombs in Na I D nor Mg I b
- SDO/AIA 1700: the pore migrated fast into opposite-polarity field
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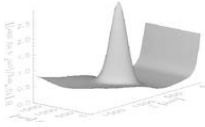
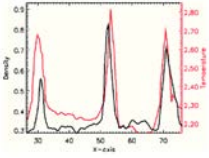
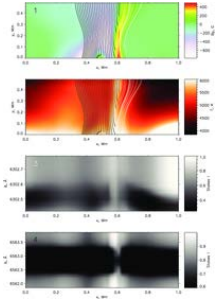
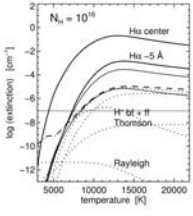
- speculation: mushroom clouds of recombining post-EB gas

ELLERMAN BOMB MODELING BEYOND CLOUD FITTING









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  - Kitai 1983SoPh...87..135K: 1D VALIIIC center-limb
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  - Berlicki & Heinzel 2014A&A...567A.110B: 1D ALC7 vertical
  - issues: above 300 km to avoid slanted EB visibility in continuum
    missing: non-visibility in Fe I, Na I D, Mg I b
    missing: visibility in IRIS C II, Si IV

- *MHD simulations*
  - Archontis & Hood 2009A&A...508.1469A: EBs but no radiation
  - Nelson et al. 2013ApJ...779..125N: radiation but no EB

- *to do*
  - explain and reproduce EB appearances comprehensively
    Hα: Holtsmark Stark and Thomson redistribution
    continuum: no brightening in slanted viewing
    IRIS lines: Mg II triplet, C II, Si IV
    Na I D& Mg I b: mushroom clouds
  - simulate 3D(t) non-E-MHD kG reconnection with 3D(t) synthesis including non-E Hα memory for instantaneous hot opacity

ELLERMAN BOMBS: CONCLUSION

"Extensive modern observations have added little to Ellerman's original description"

Bray & Loughhead (1974) "The Solar Chromosphere"

Ellerman (1917): ADS citation history — there may be hope for your non-cited discovery yet

- *spectral appearance*
  - hot: wide Balmer, Ca II electron moustaches
  - very hot: IRIS ultraviolet signatures! Na I D, MgIb mushroom clouds?
  - locate Ellerman bombs in your data? Inspect AIA 1700 x 1800
- *nature*
  - photospheric long-pull-up strong-field reconnection
  - usually no obvious explosive effect on chromosphere or higher
  - tell-tales for emerging active-region field re-arrangement
- *to do*
  - proper MHD simulation plus proper spectral synthesis
    (Holtsmark Stark, thermal Thomson redistributiion, Na I D, Mg I b, IRIS lines)
  - high resolution IRIS + GBO Hα + magnetograms: emergence topology
  - low resolution HMI $\vec{\mathbf{B}}$ + AIA UV EBs: active-region topography evolution

1

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  - photospheric jets in rapid succession along network
  - shielded in $H_{1\alpha}$ core by overlying fibrils
  - photospheric strong-field reconnection?

3

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fallacies	fads
• *EB moustaches*	• *emergence patterns*
– appear in neutral-metal lines	– serpentine Parker instability
– appear in network	– bald patches
• *EB $H_{1\alpha}$ profile*	• *anemone jets*
– dark core = bomb ingredient	– downflows and upflows
– brighter blue wing = upflow	– surges
• *EB height*	• *cartoon modeling*
– $H_{1\alpha}$ = chromosphere	
= chromospheric reconnection	
• *EB as flare*	
– downward proton beams	
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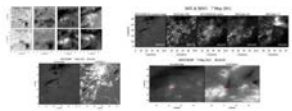

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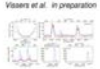

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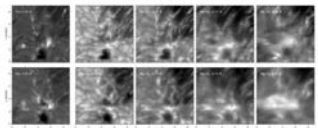

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  - proper MHD simulation plus proper spectral synthesis
    (Holtsmark Stark, thermal Thomson redistribution, Na I D, Mg I b, IRIS lines)
  - high-resolution IRIS + GBO $H_{1\alpha}$ + magnetograms: emergence topology
  - low resolution HMI B + AIA UV EBs: active-region topography evolution

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