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Properties of Impulsive Events in a Polar Coronal Hole

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Abstract. Observations made at NSO/Sacramento Peak Observatory with the 16" Coronagraph allow the analysis of fast impulsive events. Broad-band Hα filtergrams and CCD–spectra taken at 1 to 45 *arcsec* above the solar chromospheric–limb are used. A deep well-developed Coronal Hole was chosen above a Polar Region, during years of minimum of sunspot activity. We present a whole range of impulsive events observed there in 1988. They are tentatively analyzed using statistical methods and the results strongly suggest they could be the source of the fast wind. The recurrence of impulsive events is reported for the first time.

1. Introduction

During the last decade, a consensus seems to emerge among Solar Physicists to consider that fast small scale events, presumably induced by magnetic reconnection phenomena, are potential candidates to contribute to the coronal heating and the solar wind (see i.e. D. Mullan, 1991). For more than one century (!), solar observers have been aware of the irregular appearance of the chromosphere in the best conditions in the Hα line with a coronograph or even a refractor. Among the most popular work, we should remind whose of the father Secchi of "vertical flames" ("filets") in polar region of the Sun, of D. Menzel discussing large scale excellent eclipse plates and describing the "spike" prominences or small vertical polar prominences, of W. Roberts, 1944, of polar chromospheric spicules (further the terminology "spicule" has been applied to describe all fibril-like structures of the chromospheric fringe) and finally, of Sacramento Peak Observers who called these events "polar surges". Further, to avoid any confusion, we will refer to those events which occur well above the chromospheric fringe (above 6.5 Mm height) of polar regions inside a coronal hole (very low intensity coronal emission-lines region).

Spaceborne UV, EUV and X-rays imagery and spectroscopy has brought a rich amount of data concerning this topic, starting with the rediscovery of the phenomena sometimes called macro–spicule when observed above the limb. The scale of these events have not been definitely set out (macro versus micro versus nano events?) as well as their association with chromospheric surface magnetic features (network elements ; ephemeral regions ; intra–network field). Since the discovery of X–ray bright points, more high spatial, spectral and temporal resolution has been obtained by the Brüeckner et al. group at NRL with the HRTS package (see the presentation of J. Cook in the present Proceedings) : jet–like and explosive events are observed in transition line emissions, on the disc and above the limb. However, because the short duration of a rocket flight permitting such observation, no statistical analysis has been performed.

Finally, a new kind of observation of these impulsive events has emerged recently, thanks to the use of the high spatial resolution imagery made at the VLA radio–telescope (few attempts have been also made at the USSR Ratan–600) ; the long equivalent integration time needed to get a picture does not however permits to look at the details of the phenomena nor permits the collection of a statistical material.

In this contribution we address the question of both the geometrical parameters and the temporal behaviour, based on a sufficient amount of observations, of impulsive events (I.E.) ; moreover, they are exclusively observed above a well developed coronal hole, namely a polar coronal hole. It is a part of an observational effort aimed at bringing new data on the problem of both the origin of the fast wind and of the coronal heating mechanism based on observations performed during the years of the last Sunspot minimum at NSO/ Sacramento Peak.

2. Brief account (see table I) of observations

The material discussed here is based on observations performed in very good coronal days (low sky background) with the large 16" coronograph of NSO/S.P. Besides fast spectroscopic observations made above the limb in chromospheric and coronal lines, we obtained long sequences of slit–jaw broad–band (FWHM = 0.1 nm) Hα Lyot filter filtergrams. Exposure–time was always 1 sec and the exact sampling interval was 10 sec, a compromise found optimum to cover a maximum amout of events and to use moments of fair seeing. The field of view was always around the N–pole, except the last day, see table I. From the analysis of coronal maps in Fe XIV as produced at Sacramento Peak by R. Altrock and al. for these days, our observations referred to a deep well developed coronal hole (C.H.) with an extension along the limb larger than the length we analyzed here of 8 arcmin (330 Mm). The spatial resolution change depending of the time of the day and from day to day, see table I, between 1 to 3 arcsec, the scale being 20 arcsec.mm^{-1} on the original 2415 film. Several sequences were used to produce a movie which is especially usefull to show the qualitative results ; occurence of I.E. with different scales, their dynamical behaviour with short ejections, the recurrences, etc.

Table I

N°	Dates	Duration of the Sequence	Image Quality	Macro-Spikes Total Number M	Number of Recurrences R	Ratio R/M	Number of Ejections	%
		h min s						
1	09 Mai 88	6 : 03 : 27	Excell.	20	14	0.70	20	100
2	22 Mai 88	3 : 39 : 41	Fair	5	0	0.	5	100
3	30 Mai 88	5 : 04 : 52	Fair	21	16	0.76	17	81
4	09 Jun 88	5 : 18 : 00	Good	9	5	0.56	8	89
5	11 Jun 88	2 : 56 : 28	Good	10	4	0.40	10	100
6	27 Oct 88	3 : 47 : 00	Good	13	6	0.46	13	100
7	22 Nov 88	7 : 49 : 00	Fair	26	17	0.65	21	81

The quantitative analysis was based on measurements performed over individual images scanned using a video–CCD camera and a suitable display scale ; a pointer manually positionned on a monitor screen was used to collect the data ; many hard copies of different grey levels were also examined to confirm the results. Geometrical parameters are collected using what we believe is the "base" of the transition region (T.R.) : the average location of the highest radial gradient of Hα full line intensity, assuming the azimuthal small scale inhomogeneities (but the I.E.) are smeared out. Above the polar coronal hole, the height of the chromosphere is found to be at 6.5 Mm above the τ(500 nm) = 1 level of the photosphere, although in equatorial region this level is typically lower.

3. Results of the analysis of the temporal sequences

The most impressive results are contained in the movies which beautifully illustrate the activity inside a C.H. At the poster presentation we showed several examples of I.E. using consecutive prints ; here we show results coming from the histogram or correlogram analysis of more than 100 individual I.E.

I.E. can be clearly classified in 2 broad families of well separated events ; small one or tiny and faint events seen only on the best high resolution short sequence, and the large one or macro–spikes, occuring above more complicated low level surge–like phenomena.

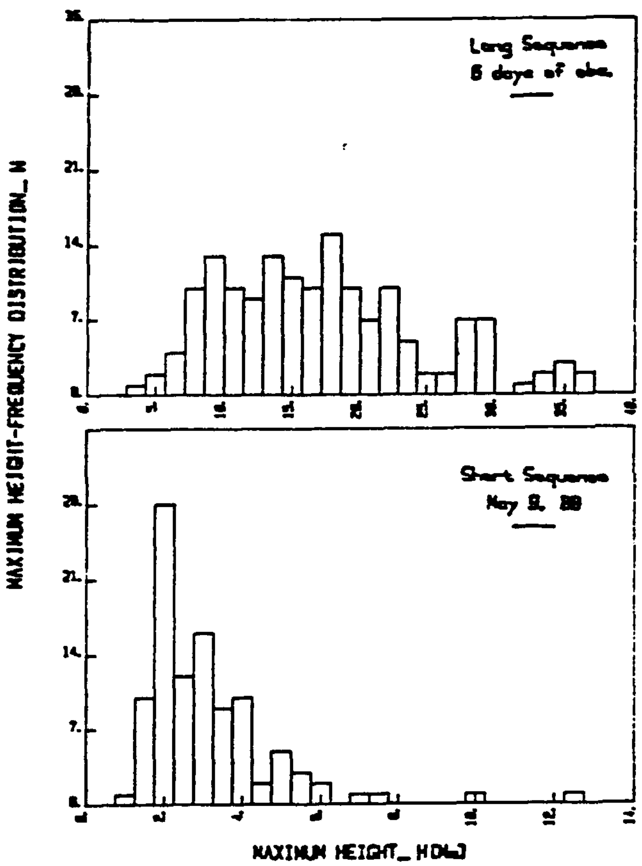

Fig. 1

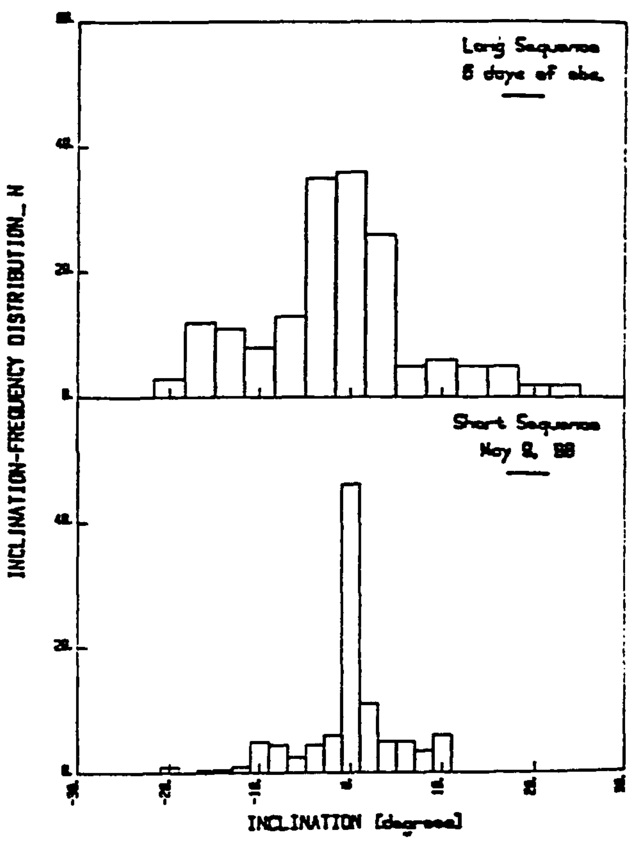

Fig. 2

Figure 1 shows the histograms of heights (above the T.R. "limb") reach by I.E. observed in Hα. For the 1st class of I.E., typical heights are 3 Mm ; for the 2nd class they reach 35 Mm with average values around 17 Mm.

Figure 2 shows the histograms obtained measuring the inclination of I.E. compared to the exact radial direction from their feet : the dispersion around the radial direction is very small for the 1st class tiny events and slightly broader for large events. We remind that outside a C.H. this dispersion is far larger. Figure 3 is the result of the analysis of the "spacing" between I.E.: for each sequence of observation we integrate the whole sequence and measure the shortest distance between the feet of 2 I.E.

Figure 4 is the result of the analysis of the recurrences we observed: I.E. occuring twice or more times from apparently the same location of the limb. Note that the scale of time–intervals is not the same for the tiny I.E. than that for the large I.E.

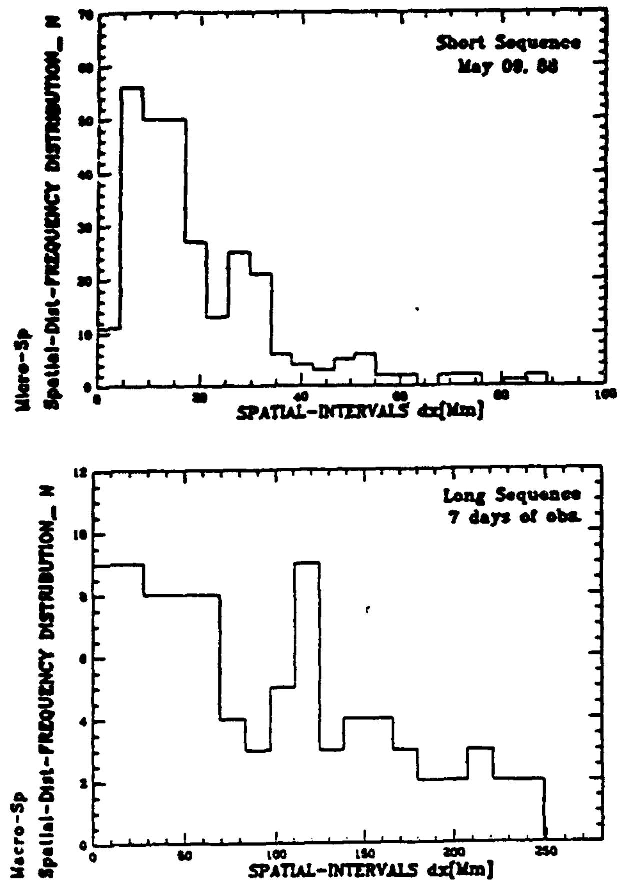

Fig. 3

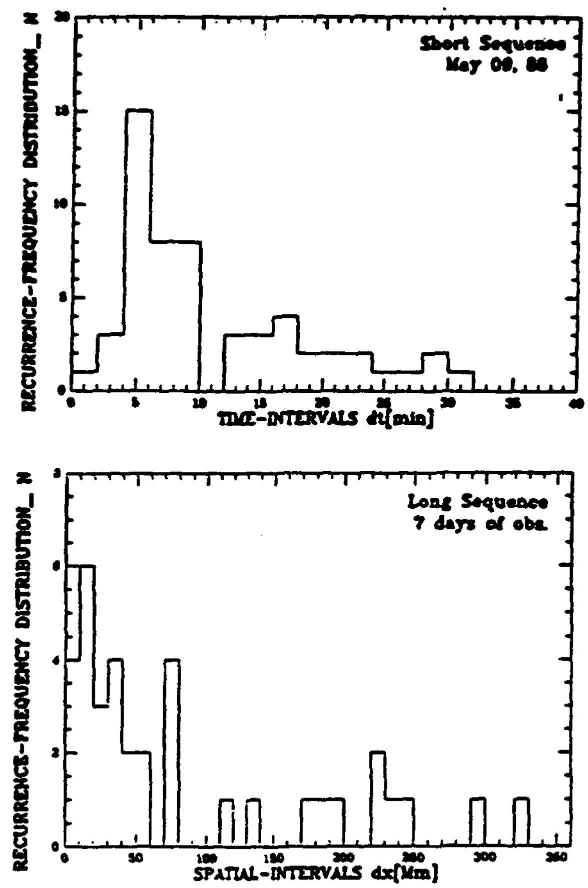

Fig. 4

Finally, figure 5 shows the distribution of the full life–time of I.E. again with a clear difference between tiny and large I.E. Note that the life–time is counted from the moment of emergence of the I.E. above the T.R. limb until the disappearance of the part of the I.E. situated at the top of the ejection phenomena.

4. Discussion and conclusions

The distribution of I.E. as a function of their radial extension (heights), as a function of the average spacing between the events and as a function of the life–time confirms the existence of 2 classes of I.E. Recurrences have been observed up to 4 times and with the most probable time interval of 20 min. A very detailled analysis of single small I.E. has also shown a quasi–oscillatory behaviour of several parameters during the ejection ; periods are between 30 and 50 sec of time.

We can now reconstruct the behaviour of a typical I.E.:

- It reaches the corona and become fully ionized,
- The rising time is short, of order of 1 min,
- Oscillations are present (T $\sim$ 40 sec),
- A recurrence occurs at a time interval of order of 20 min,
- The ejection phenomena is strictly radial.

The last figure 6 is a cartoon we propose to explain the overall properties of I.E. observed in C.H. ; large I.E. are certainly co–spatial with network elements, as suggested by the distribution of their spacing on figure 3 (average distances of 30, 60 and even 120 Mm are observed). However, more adapted observations are needed to confirm this claim. The origin of the presumably explosive phenomena responsible for the I.E. is not yet well established, although a

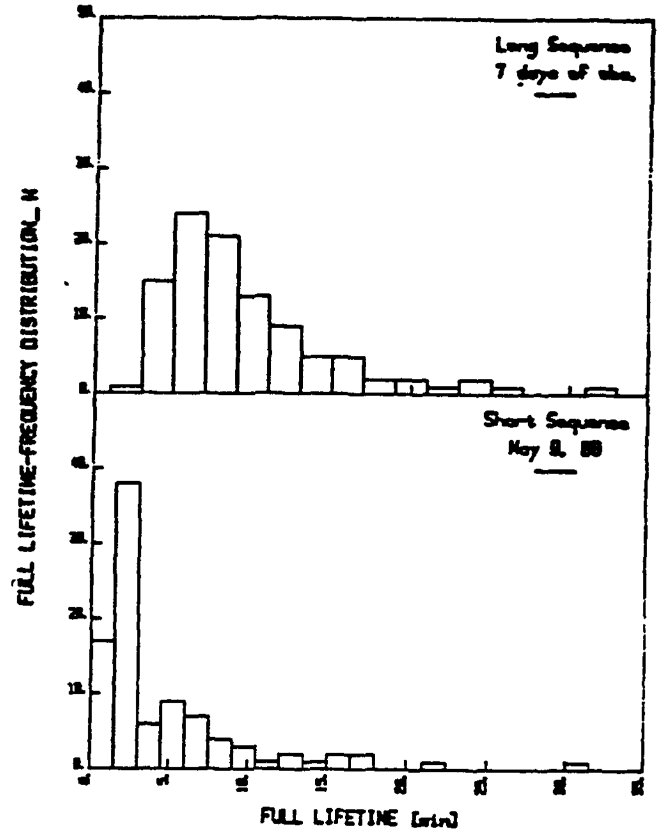
Long Sequence
7 days of obs.
Short Sequence
FULL LIFETIME-FREQUENCY DISTRIBUTION N
FULL LIFETIME [min]

Fig. 5

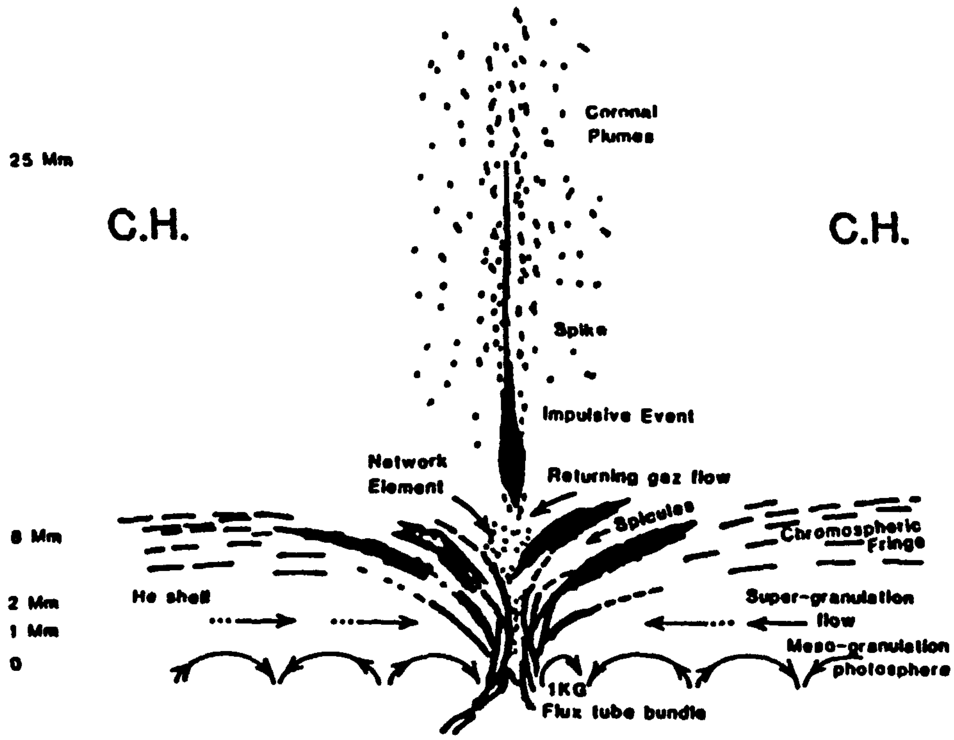
25 Mm
C.H.
C.H.
Coronal
Plumes
Spike
Impulsive Event
Network
Element
Returning gaz flow
Spicules
Chromospheric
Fringe
8 Mm
2 Mm
1 Mm
0
He shell
Super-granulation
flow
Meso-granulation
photosphere
1KG
Flux tube bundle

Fig. 6

mechanism based on the reconnection of magnetic field lines is certainly the best candidate ; a further acceleration in radial direction is possible thanks to the so-called diamagnetic acceleration mechanism, see Pneumann, 1983 ; models should better reproduce the apparent connection between I.E. feet and coronal polar jets or plumes and give predictions of the cross-section of jets and also of the amount of material which is pushed away. Finally, the recurrence of I.E. is reported for the first time and models should incorporate this new parameter.

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Mullan, D.J.: 1991, present proceedings.
Pneumann, G.W.: 1983, *Ap. J.* **265**, 468.
Roberts, W.O.: 1944, *Ap. J.* **101**, 136.

Discussion

Mullan: Your events may be macrospicules. These were observed in coronal holes with Skylab as places of energy release. Association between mass loss and polar plumes was made by Ahmad and Webb (1978, Solar Phys.) and interpreted as reconnection impulsive events by Mullan and Ahmad (1982, Solar Phys.). In the latter model, repetitiveness is expected at each site.

Answer: Since the discovery of the chromosphere at eclipses by J. Janssen and Lockyer, more than 120 years ago, hundreds of papers have been written on that topic. Our contribution is based on long time sequences (up to 7 hours) and the consideration of both small scale and large scale events above the chromospheric limb of a polar coronal hole. These observations are made without any interruption like the SkyLab observations are and they have a better temporal resolution which makes possible the analysis of short period phenomena. Unfortunately, we do not have simultaneous magnetic field measurements which are very difficult to make in the inner corona ; for that, we would need a large aperture coronograph, at least at ground base, to confirm the "magnetic reconnection" hypothesis. Such instrument, based on the success of Mirror Advanced Coronographs (see Smartt and Koutchmy 1990, SPIE Symposium) is planned at Sacramento Peak Observatory with the Zeeman and Hanle effects magnetograph as a focal plan instrument. Repetitiveness you predict in your model is probably the recurrence we definitely saw in our analysis.

Habbal: Do you have any observational evidence that there were coronal bright points underlying these events?

Answer: The evidence is coming from the statistical analysis of the spacings between large impulsive events. Taking into account the effect of line of sight integration, we found the distribution of spacings corresponds to what is expected if these events are co-spatial with the polar network elements. In the case of small events, the distribution is quite different. The connection between chromospheric and coronal spikes is given by eclipse observations (Koutchmy and Stellmacher 1977, Solar Phys.). Other evidences are coming from the NRL-group (Brueckner et al.) rocket observations (on the disc) of jet-like phenomena. To observe the small scale underlying region (under I.E.) we would need a large aperture coronograph (see the answer to the question of D. Mullan).

Ulmschneider: What is the relation of your events with spicules?

Answer: Spicules are presumably inside the chromospheric fringe which is raising up to an average distance of 6.5 Mm above the photosphere ; in coronal holes, this distance is a little bit larger. The events we consider are definitely above the chromospheric fringe ; for large events the average distance they reach above the fringe is 25Mm, i.e. 32Mm above the photosphere ; additionally, they are straight and vertical ; compare to spicules, they are rare events.

Hollweg: Can you elaborate on the connection of these events with the solar wind, as you promised in your introduction?

Answer: We have more data – not presented here – showing these events provide the material for polar plumes with a typical spacing (30 and 60 Mm). This spacing has been also identified in the fast wind using Helios spacecraft in–situ measurements (MPI–Lindau), so we believe the signature of impulsive events exist in the fast wind. Because the Hα emission of I.E. becomes fainter and fainter due to both the ionization going on in the plasma and to the Doppler diming effect ($v > 150$ km sec^{-1}), coronal lines should be used further in the corona to see the interface with the solar wind. We have observations taken in the FeX red line in the polar coronal hole showing the same order of magnitude velocities.