Astron. Astrophys. 363, 279–288 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Results from a revisit to the K_{2V} bright points

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Received 12 July 2000 / Accepted 31 August 2000

Abstract. We have used pairs of temporally simultaneous CaII K-line spectroheliograms and magnetic area scans to search for spatial correlation between the CaII K_{2V} bright points in the interior of the network and corresponding magnetic elements. We find that about 60% of the K_{2V} bright points spatially coincide with magnetic elements of flux density > 4 Mx cm^{-2}. About 25% of the K_{2V} bright points with equally enhanced emission lie over bipole elements where the fields are > 4 Mx cm^{-2} for both polarity elements which merge and presumably cancel and result in low fields. The rest, 15%, of the bright points coincide with areas of fields < 4 Mx cm^{-2} which is the noise level set by us for the magnetic scans. When magnetic elements of opposite polarity merge and form bipoles, the associated K_{2V} bright points show excess emission. Although such excess emission is a magnetic-field-driven phenomenon, the measured value of the field at the site of the bipole is typically low, and these cases would therefore be excluded in the count of coincidences of excess emission with excess magnetic fields. In our opinion, these cases of excess emission at the sites of the bipoles, as well as at the sites of fields > 4 Mx cm^{-2}, are both instances of magnetic-field-related emissions. If the former are not taken into account as coincidences, the correlation will drop down and this might be interpreted as not an obvious correlation. Our present results, taking into account the low fields of merging bipoles, establish the association of K_{2V} bright points with magnetic elements.

Key words: Sun: chromosphere – Sun: magnetic fields

1. Introduction

The solar chromosphere is highly structured at various spatial scales and observations and theory point to the fact that the magnetic field is the agent responsible for this structuring. The H and K lines of singly ionized calcium are the proven best spectral diagnostics from the ground to probe the physical conditions of these structures in the chromosphere of the sun (Rutten & Uitenbroek 1991) as well as the chromospheres of sun - like stars (Wilson & Bappu 1957; Bappu & Sivaraman 1977; Noyes 1981 and the references therein).

On a two-dimensional image of the sun in the H or K line, the structures seen in emission in the quiet chromosphere are the network and the bright points that populate the interior of the network. Plages are an active region component with striking emission that appear during the years of solar maximum (Hale & Ellerman, 1903; Bappu & Sivaraman, 1971; Zirin, 1974). Of these, the plages and the active network as well as the network on the quiet sun are cospatial with the photospheric magnetic fields (Leighton, 1959). Furthermore, the brightness of the network bears a linear relation with the underlying photospheric magnetic field with which it is cospatial (Skumanich et al. 1975; Stenflo & Harvey, 1985). An excellent review of the properties of K_{2V} bright points in the interior of the network (also called the K_{2V} grains) exists in the literature (Rutten & Uitenbroek, 1991 and the references therein). Magnetic elements in the interior of the supergranular cells, although detected as early as 1975 by Livingston & Harvey (1975), have attracted renewed interest in the last decade because of the possibility of measuring these small-scale fields, with improved precision (Keller et al., 1994; Wang et al., 1995; Lin, 1995). These magnetic elements in the interior of the supergranular cells are referred to as intranetwork fields by Keller et al. (1994), Zhang et al. (1998b, 1998c) and as internetwork fields by Lites et al. (1999). Now, the important question is whether these K_{2V} bright points (referred to as INBPs in this paper) are cospatial with the magnetic elements (referred to here as IN magnetic elements) or not.

Direct evidence for the spatial correspondence between the INBPs and IN magnetic elements was provided by Sivaraman & Livingston (1982). They compared Fe I 8688 Å magnetic scans with sequential 1.1 Å band pass K-line scans both obtained at the vacuum solar telescope on Kitt Peak.

They found that:

1. the INBPs spatially correspond to the IN magnetic elements,
2. the fields of the associated IN magnetic elements are in the range 10–20 Mx cm^{-2}, the maximum fields reaching 70–80 Mx cm^{-2},
3. the INBPs have no preference for either polarity, and
4. there are many IN magnetic elements which do not have corresponding INBPs.

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However, some authors report that the INBPs are of hydrodynamic origin and bear no correlation with the IN magnetic elements. Steffens et al. (1996) found that some of the INBPs travelled within the network cells with horizontal speeds of 30–80 $\mathrm{km\,s^{-1}}$, comparable to the phase velocity of the solar p-modes and the spatial distribution of the INBPs showed no prominent clustering within the network. Based on these results, they concluded that the INBPs are just the prominent peaks of the p-mode wave field and have therefore no correlation with the IN magnetic elements. However, Wellstein et al. (1998) recent measurements show that the INBPs move with horizontal velocities 6–8 times smaller than the values of Steffens et al. (1996). Remling et al. (1996) reached the conclusion that K_{2V} grains are non-magnetic phenomena from their analysis of simultaneous spectral scans in the CN band (3883 Å) and the K-line. They used the CN scans as proxy for magnetic flux and did not find any statistically significant increase in CN intensity at those locations where the K-line INBPs appear.

All these conclusions are from observations that do not contain measurements of magnetic field and must be considered indirect evidence. This controversy according to Rutten has now been resolved (Rutten, 1996; Hoekzema, 1997) by the hydrodynamic simulations by Carlsson & Stein (1997, 1998). The propagation of acoustic waves through a non-magnetic chromosphere reproduces the dynamical evolution of the H-line profiles of the INBPs very well. According to this scenario, the INBPs are due to the interference between the shocks in the upward propagating acoustic waves with the back-falling material of the previous shocks and these are of non – magnetic origin and have a stochastic distribution within the network. On the other hand, Kalkofen (1996 and references therein) favours an impulsive excitation at the site of the IN magnetic elements as a plausible mechanism for the 3-minute oscillations in K_{2V} emission in the bright points since other mechanisms like chromospheric cavity or the Lighthill mechanism cannot explain either the temporal or spatial intermittancy in the emission exhibited by the INBPs. He argues in favour of a possible connection between the INBPs and the IN magnetic elements on the basis of the positional stability of the K_{2V} bright points, on the equality of the numbers of the INBPs and the IN magnetic elements within a cell and the agreement between the magnetic field values estimated by him and those measured for the IN magnetic elements (Keller et al., 1994; Lin, 1995).

The way to resolve this controversy is to obtain K-line and magnetic field observations and look for correlations or their absence. The only attempt in the recent past in this direction is by Nindos & Zirin (1998) where they analysed two sets of K-line filtergram and deep magnetogram pairs and concluded that there are two classes of intranetwork bright points: one associated with intranetwork magnetic fields and the other not associated. While we were in the final stages of completing this paper we came across another attempt by Lites et al. (1999) using the Stokes V data from the Advanced Stokes Polarimeter and H_{2V} spectra obtained synchronously at the NSO / Sacramento Peak Dunn Solar Telescope with the aim of "utilising spectrographic techniques to enhance the measurement accuracy at the expense of field of view". Specifically they compare the H_{2V} index (the H-line intensity index over a 0.008 nm wide band displaced from line center by $\Delta\lambda$ = 0.016 nm) and the Stokes V profile space-time charts for a "small internetwork area" and find that "there is no obvious association of H_{2V} brightenings with either localized field excesses or with field deficits".

In this paper we report new observations of K_{2V} INBPs and IN magnetic elements and demonstrate that the two structures do show spatial correspondence. Our study points out in particular the possibility of misinterpretation without some key insights. In the cases of excess K_{2V} emission associated with bipoles, the magnetic field measurements do not show up because of their intrinsic low fields. However, if such cases are not included for this reason, then the percentage of coincidences of K_{2V} or H_{2V} bright points with magnetic fields will be lower and this could be interpreted as a no obvious correlation. On the contrary, when the cases of bipoles are included, then the percentage of coincidences rises as high as 85%.

2. Observations and reductions

We (Sivaraman, Livingston and Gupta) have been collecting data from new observations every year from 1993 to 1997 with the primary aim of securing high-quality observations under the best seeing conditions possible. These observations consist of a sequence of spectroheliograms in the K-line at the East Auxiliary facility of the McMath-Pierce telescope and temporally simultaneous magnetic area scans using the spectromagnetograph (Jones et al., 1992) at the Vacuum Telescope closeby. A spectroheliograph for use at the focal plane of the spectrograph of the McMath - Pierce telescope was fabricated by Keith Pierce especially for these observations. These scans covered quiet regions around the centre of the disk. Among the observations collected over the years, the ones of April 16, 1994 are the best. The exit slit of the spectroheliograph was set at 400 μm which corresponds to a band pass of 40 mÅ positioned on the K_{2V} emission peak. The spectroheliograph scanned an area of 560 $\times$ 440 arc sec^2 on the sun in 30 seconds while the duration of the magnetic scans that covered an area of 700 $\times$ 512 arc sec^2 over the same region on the sun was about 5 minutes. The spectroheliograms (abbreviated as SHGs henceforth) were obtained on T-Max 400 Kodak films and were developed in D19 for 5-min. The magnetic scans were obtained with 26 integrations, twice the normal value adopted for the synoptic observations and this improved the S/N ratio by a factor of $\sim$1.4.

From the sequence of 10 K-line SHG and magnetic scans obtained on April 16, 1994, three K-line SHGs that temporally coincided with the three magnetic scans, constituting three K-line SHG – magnetic scan pairs, (designated pair 1, 2 and 3) were chosen for a detailed analysis (Table 1). Because of the narrow passband centred on the K_{2V} emission peak, the INBPs and the network stand out strikingly in emission in comparison with broad-band filtergrams. On our scans, there are about 15 INBPs per cell and we also notice that there is diffuse emission less bright than the INBPs almost everywhere within the network (see also Hale & Ellerman 1903, Fig. 3 of Plate IV), which

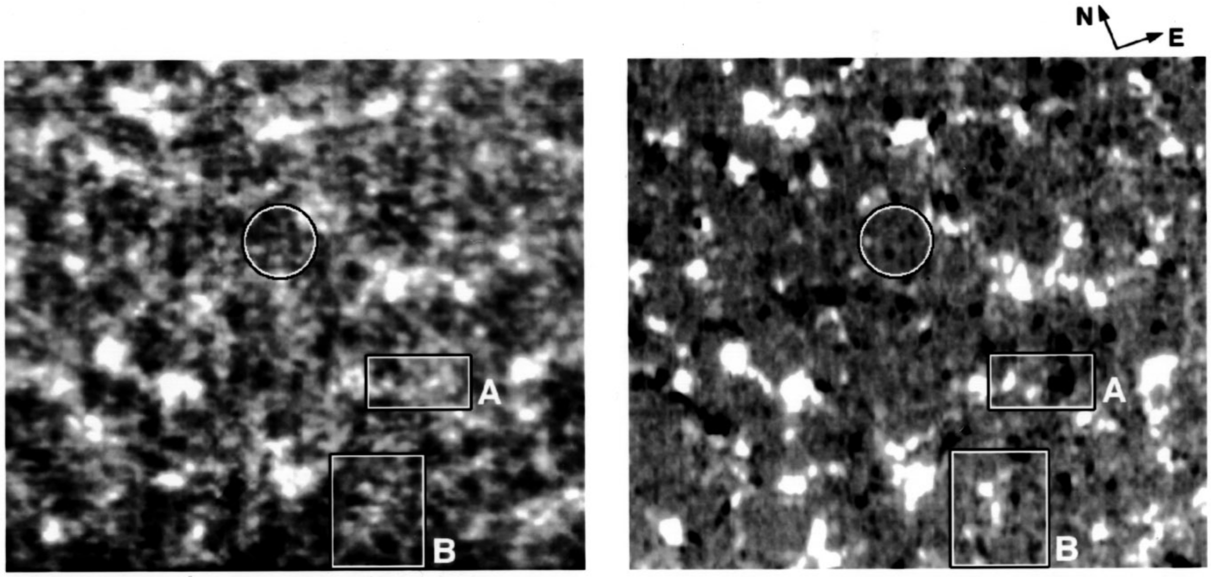

Fig. 1. A section of the K_{2V} spectroheliogram (left) and the coaligned magnetic area scan (right) pair. An example of the innernetwork bright points (INBPs) in the SHG that are cospatial with the innernetwork magnetic elements is shown within the circle (of diameter 30 arc sec) in the respective frames. There is a striking example of a bright INBP just below the centre of the circle that coincides with a negative polarity field. There is another INBP at the 9 o′clock position that coincides with a positive-negative polarity pair. The third one at the 3 o′clock position coincides with a positive polarity element and the fourth one approximately at the 4 o′clock position coincides with a negative polarity element. Examples of the Network Bright Points (low brightness) can be seen within boxes A and B.

Table 1. Details of the scans of April 16, 1994. The times are in Mountain Standard Time (MST).

Pair No.		Spectroheliograms (SHG)			Magnetic scans		
		h	m	s	h	m	s
1.	Start	07	34	30	07	34	04
	End	07	35	00	07	39	04
2.	Start	07	41	30	07	39	44
	End	07	42	00	07	44	44
3.	Start	07	46	00	07	45	24
	End	07	46	30	07	50	24

shows the “minute calcium flocculi” and the diffuse emission at the “H_2 level”. These diffuse emissions do not show up in the filtergrams with a broad band pass. At the time of minimum of solar activity the network elements, which consist of only the “quiet sun network” component, do not form a continuous boundary in all the cells, but are broken in between, giving an impression that the cells are incomplete. This is because the coarse mottles (De Jager, 1959) that form the additional network component are virtually absent during a deep solar minimum, whereas during other phases of the solar activity, even the regions considered quiet do contain a significant amount of the coarse mottles on the network boundaries along with the quiet sun network component which clearly defines the cell boundaries.

The K-line SHGs were digitized at the same resolution as the magnetic scans (1.14 arc sec per pixel). The analysis of the K-line SHG and magnetic scan pairs was done using the IRAF software system. The entire field of the two images forming a SHG – magnetic scan pair was divided into 4 subfields to ensure the best registration of the image pairs. The subfield was registered to $\sim$ 1.2 to 1.4 pixels. The bright points within the network were identified visually. A cursor was placed on a bright point and the brightness (film density) was recorded. We then flipped to the magnetic image and recorded the magnetic field at the same co-ordinates. This was done for all the INBPs in the whole sub-field identifying the INBPs one by one. We show in Fig. 1 the INBPs and the spatially-coincident magnetic elements in one area bounded by the circle as an example. Those elements that resembled the INBPs, but lay very close to the network boundary and so could have a possible membership with the network, were not included in the measurements; only those bright points that lay clearly within the network were measured. The brightness of each INBP is the maximum value over a 2×2 pixel area and the magnetic field for each IN magnetic element is the maximum absolute value of the field over the same 2×2 pixels in Mx cm^{-2}. We repeated this measurement procedure for the three SHG - magnetic scan pairs.

Using a very narrow spectral band to isolate the K_{2V} emission peak, the number of INBPs per cell ranges from 10 to 20 and on most occasions it is closer to the latter figure. With this number of bright points, the interior of the network looks very crowded. Similarly, in the magnetic scans we see almost the same number of IN magnetic elements within each network as the INBPs. Thus it is a challenge to look for coincidences (or their absence) in crowded fields in the image pairs.

One way to rule out the possibility of chance coincidences is to reduce the population of the INBPs and also the diffuse emission within each cell and then look for coincidences. To do this we applied a threshold in brightness, to the K_{2V} Spectroheliograms mentioned in Table 1 and derived brightness images with only those INBPs left within the network that have brightness $> 1.5\ \bar{I}$ (or 50% above $\bar{I}$), where $\bar{I}$ is the mean brightness over the network interior. We did the brightness – magnetic field measurements for all the INBPs that were now in the field. In the next step, we increased the threshold to 70% of $\bar{I}$ and derived images with only those INBPs having brightness $> 1.7\ \bar{I}$. The measurements of the brightness – magnetic field were again done as before for all those INBPs remaining in the field. The brightness – magnetic field measurements were done for the three brightness threshold levels for the 3 SHG – magnetic scan pairs listed in Table 1. We wish to emphasise that we have made the coincidence measurements only on the INBPs and not on the diffuse emission regions. Another way to rule out the chance coincidence is to compare the INBPs of a cell with the IN magnetic elements of another cell in a different region on the sun.

The noise level in the magnetic scans was determined from a set of simultaneous magnetic scans obtained at the spectromagnetograph as well as at the McMath – Pierce telescope using ZIMPOL I (Keller et al., 1994) over a quiet area around the solar disk centre on another occasion. The noise level from a comparison of these scans (using the ZIMPOL I scans as the reference standard) is about 3 $\mathrm{Mx\,cm^{-2}}$. This value is consistent with the increased integration time we used for the magnetograms that improved the S/N ratio by a factor of 1.4. However, we have set the noise level for our present measurements at 4 $\mathrm{Mx\,cm^{-2}}$, a more conservative value which is the value normally used for the NSO magnetograms in all studies.

As we have described in our search for coincidences, we have read the maximum absolute value of the magnetic fields over a 2×2 pixel area for every IN magnetic element examined (which is the counterpart of an INBP) to decide whether the coincidence is with fields $> 4\ \mathrm{Mx\,cm^{-2}}$ or $< 4\ \mathrm{Mx\,cm^{-2}}$. Note that the lower detection limit for the flux corresponding to the noise level of 4 $\mathrm{Mx\,cm^{-2}}$ would be about $2\ 10^{16}$ Mx. In addition, to have an idea of the magnetic environment around the 2×2 pixel area, we examined the field over a 10×10 pixel area centered around the 2×2 pixels which provided us the magnetic field of the IN magnetic elements. In all cases where the fields exceeded 4 $\mathrm{Mx\,cm^{-2}}$ over the 2×2 pixels it was found that the field values outside the 2×2 pixels were also high and of either polarity. We also noticed that at each brightness level about 25% of the INBPs (as bright as the ones associated with fields $> 4\ \mathrm{Mx\,cm^{-2}}$) coincided with magnetic elements (over the 2×2 pixel) with fields $\leq 4\ \mathrm{Mx\,cm^{-2}}$. In such cases it was evident from the 10×10 pixel matrix that the 2×2 pixel area lay at the interface of merger of two opposite polarity elements, while the fields outside the 2×2 pixels were far above 4 $\mathrm{Mx\,cm^{-2}}$ for both polarities. Thus these represent the meeting places of opposite polarity fields which eventually cancel, and examples of such cancellations have been illustrated well by Zhang et al. (1998b) and the increase in brightness of the INBPs above the sites of bipoles by Nindos & Zirin (1998). We are not able to follow the evolution of cancellation events as our data do not form a time sequence. But from an examination of the pixels in the immediate neighbourhood of the 2×2 pixels we are able to infer the cancellation of the opposite polarity fields and there are several such cases in our large sample. Zhang et al. (1998b) estimate that about 30% of the IN magnetic elements cancel with magnetic elements of opposite polarity at any time, and this is in agreement with the data reported here. The rest 15% of the INBPs lay over areas where the fields were much lower than 4 $\mathrm{Mx\,cm^{-2}}$ both over the 2×2 pixels as well as in the neighbouring areas. These probably represent the unresolved emission and unresolved fields within the network.

3. Results and discussions

The results of our measurements are presented in Table 2. The important results of this study are that for all 3 brightness levels

1. about 60% of the INBPs with strong emission spatially coincide with IN magnetic elements of flux density $> 4\ \mathrm{Mx\,cm^{-2}}$,
2. about 25% of the INBPs with strong emission lie over areas where opposite polarity IN magnetic elements with flux densities $> 4\ \mathrm{Mx\,cm^{-2}}$ meet, merge and cancel resulting in fields with values $< 4\ \mathrm{Mx\,cm^{-2}}$, and
3. the rest, 15% of the INBPs lie over areas with fields $< 4\ \mathrm{Mx\,cm^{-2}}$, which is the noise level set by us for the magnetic scans used in the present analysis.

Our study shows that if those magnetic elements of flux density $> 4\ \mathrm{Mx\,cm^{-2}}$ alone are used, the coincidences are 60% which may not appear as a striking correlation. In the case of bipoles, although the fields are $< 4\ \mathrm{Mx\,cm^{-2}}$, the INBPs associated with them show strong emission. Nindos & Zirin (1998) have many instances in their time series where magnetic elements of opposite polarity move towards each other, merge and form bipoles accompanied by significant increase in emission in the associated INBP. Although such an increase in emission is a magnetic-field-driven phenomenon, since the measured value of the field at the site of the merging bipole is inevitably low (and hence will not be recorded by magnetographs however precise the measurements be) such cases would be left out in the search for coincidences of excess emission with excess magnetic fields. It is our opinion that the cases of excess emission at the sites of the bipoles as well as those at the sites of fields $> 4\ \mathrm{Mx\,cm^{-2}}$ are both instances of magnetic-field-related emission although they might possibly differ in the details of the precise role of the magnetic fields in producing the emissions. Hence if the cases of bipoles are not taken into account as coincidences, then the correlation will drop down to that extent. Lites et al. (1999) looked for the spatial correlation using their H_{2V} brightness modulation and magnetic flux density space - time charts and conclude that there is no obvious spatial correlation between the bright H_{2V} locations and magnetic field enhancements. Their analysis does not take into account the cases of emission associated with bipoles and hence they find “no obvious association”. According to our analysis the coincidences

Table 2. Results of the measurements of INBPs and IN magnetic elements. No. of cells: 106

		Total No. of INBPs	No with field > 4 ($\mathrm{M}\times\mathrm{cm}^{-2}$)	No with field < 4 ($\mathrm{M}\times\mathrm{cm}^{-2}$) bipolar	No. with field $> 4 \& < 4$ ($\mathrm{M}\times\mathrm{cm}^{-2}$) bipolar	No. with field < 4 ($\mathrm{M}\times\mathrm{cm}^{-2}$) non-bipolar
1.	All INBPs	1610	945	375	1320	290
	(All innernetwork bright points)		58.7%	23.3%	82.0%	18.0%
	No./cell	15.2	8.9	3.5		2.7
2.	INBPs $> 1.5\ \bar{I}$	826	496	209	705	121
			60.1%	25.3%	85.4%	14.6%
	No./cell	7.8	4.7	2.0		1.1
3	INBPs $> 1.7\ \bar{I}$	533	329	116	445	88
			61.7%	21.8%	83.5%	16.5%
	No./cell	5.0	3.1	1.1		0.8

of INBPs with magnetic elements without counting the bipole cases are only 60% which is not a high figure. What we have done in addition (and what they have missed) is to add the cases of bipole associated K$_{2V}$ emission and show this increases the percentage of coincidences to 85%. Thus our present analysis adds a new dimension in finding a solution to this problem by emphasising the need to include the cases of bipole associated emissions while looking for coincidences (or otherwise). We have estimated the percentage of chance coincidence by looking for coincidences of INBPs in 24 cells with IN magnetic elements in 24 cells in a different region on the sun. We find that the mean chance coincidence is about 28%, which is less than half the percentage of true coincidences.

In Fig. 2 we present the scatter plot of the brightness of INBPs vs magnetic field density, of all INBPs that show coincidences with IN magnetic elements. Similar plots for INBPs $> 1.5\ \bar{I}$ and INBPs $> 1.7\ \bar{I}$ (not shown here) appear very similar to Fig. 2 except that the density of data points is correspondingly less. A large part of the scatter is due to the 3-min oscillations, which we have not filtered as our data do not form a time sequence suitable for filtering. This scatter does not permit us to obtain a correlation between the brightness and magnetic fields even if it exists on the sun. The vertical line in Fig. 2 represents the 4 Mx cm^{-2} limit, which is the noise level set by us for the magnetic scans. The INBPs to the left of this line contain those associated with bipoles as well as the unresolved emission features with low fields. The population density of the INBPs drastically falls above the 10 Mx cm^{-2} level, whereas Sivaraman & Livingston (1982) noticed an association with magnetic elements in the range of 10–20 Mx cm^{-2}, the maximum fields reaching 70–80 Mx cm^{-2}. Whether the fields of IN magnetic elements are intrinsically low during the solar minimum and climb to higher values during solar maximum may be a point of interest for a future investigation.

We now proceed to provide additional evidence in support of our results from a variety of observations reported in the literature by other workers, particularly those from the studies on innernetwork magnetic fields such as flux distribution, motion patterns, lifetimes and finally on their relation to INBPs, in recent years from Big Bear Solar Observatory using high-quality deep magnetograms and co-temporal K-line filtergrams.

1. The mean number of IN magnetic elements (> 4 Mx cm^{-2} level) in many cells in our magnetic images is 17. It is encouraging to note that the mean number of IN magnetic elements per cell (above the noise level) from the BBSO deep magnetograms is 20 (Wang et al., 1995). This equality of the numbers of INBPs and IN magnetic elements has been used by Kalkofen (1996) for postulating on the possible spatial correspondence between the two structures. The K-line observations by Sivaraman & Livingston (1982) used a band pass of 1.1 Å. This wide passband itself will impose a high threshold and cut off a substantial number of INBPs. Thus, there would be an excess of IN magnetic elements (as no threshold was applied to the magnetic scan images) within each cell over the INBPs and, so, while looking for coincidences, it is to be expected that many IN magnetic elements would be found that do not have corresponding INBPs. This is what they noticed.
2. Nindos & Zirin (1998) find that the INBPs associated with IN magnetic fields possess horizontal velocities of the order of 1 km s^{-1}, while Zhang et al. (1998a) find from their deep magnetograms that the IN magnetic elements move within the network with horizontal velocities of almost of the same order.
3. Damé (1984), from an analysis of a 52-min long time sequence of 1.2 Å band pass K-filtergrams (obtained at the DST, Sacramento Peak), concluded that the INBPs recur mostly at the same location within the cell for this duration and they do not occur at random. He interprets this as suggesting their association with an underlying structure which possibly could be magnetic flux tubes. Since the IN magnetic elements have much longer lifetimes (Zhang et al., 1998c) the possibility of this association cannot be ruled out from lifetime considerations.
4. According to Wang et al. (1995) most IN magnetic elements emerge as clusters of mixed polarities from an emergence centre within the network. Zhang et al. (1998b) have studied

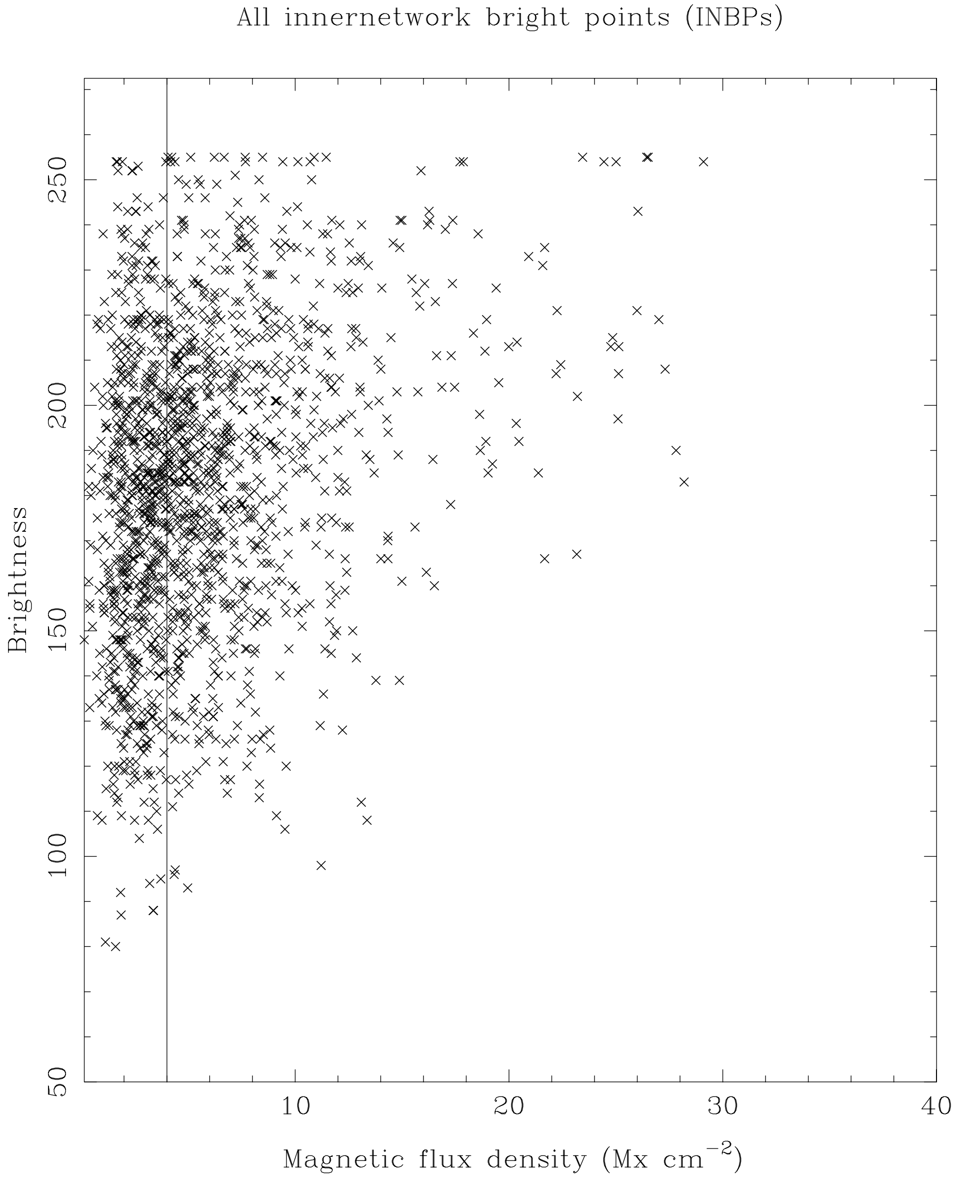

Fig. 2. Scatter plot of the maximum brightness of the INBPs vs the maximum absolute value of the magnetic field of the cospatial IN magnetic elements over an area of 2 × 2 pixels. The vertical line represents the 4 Mx cm^{-2} limit. The data points to the left of this line contain both the INBPs that coincide with bipoles (with fields $<$ 4 Mx cm^{-2}) as well as those with weak unresolved fields $<$ 4 Mx cm^{-2} (see text for details).

the evolution of the IN magnetic elements using a 10-hour long deep magnetogram time sequence at BBSO and arrive at a similar conclusion. We have made a detailed examination of the excellent K_{2V} spectroheliogram near the limb obtained by Bruce Gillespie on September 17, 1975 with the spectroheliograph set up at the East Auxiliary facility that existed at that time at the then McMath telescope. We find instances of the cluster formation (like the rosette in H_α) within the network cells in Gillespie's spectroheliogram, that are similar in appearance to the clusters in the IN magnetograms described by Wang et al. (1995) and Zhang et al. (1998b). In Fig. 3 we show one example (frame 6) of these clusters from Gillespie's spectroheliogram.

5. Nindos & Zirin (1998) and Zhang et al. (1998b) have seen bipoles within the network and according to Martin (1988) the intranetwork fields might consist of several small loops. We have identified in Gillespie's spectroheliogram instances of short fibril structures or small loops running from one INBP to its neighbour. In Fig. 3 (frames 1 to 5) we show five examples of such short fibrils (or loops). The fibril structure or the loop provides a strong evidence for the INBP - IN magnetic field association. Such fibril structure might be a common feature with all opposite polarity elements that are close to each other, but only a spectroheliogram near the limb (curved geometry), and of exceptional quality, can show these with such clarity as Gillespie's.

4. Network bright points (low brightness)

In the course of our measurements we noticed emission points located unmistakably on the network boundaries that look very much like bright INBPs. We call these network bright points (low brightness) and abbreviated as NBPs (low brightness) to distinguish them from the conventional elements that form the quiet sun network which we call network bright points (high

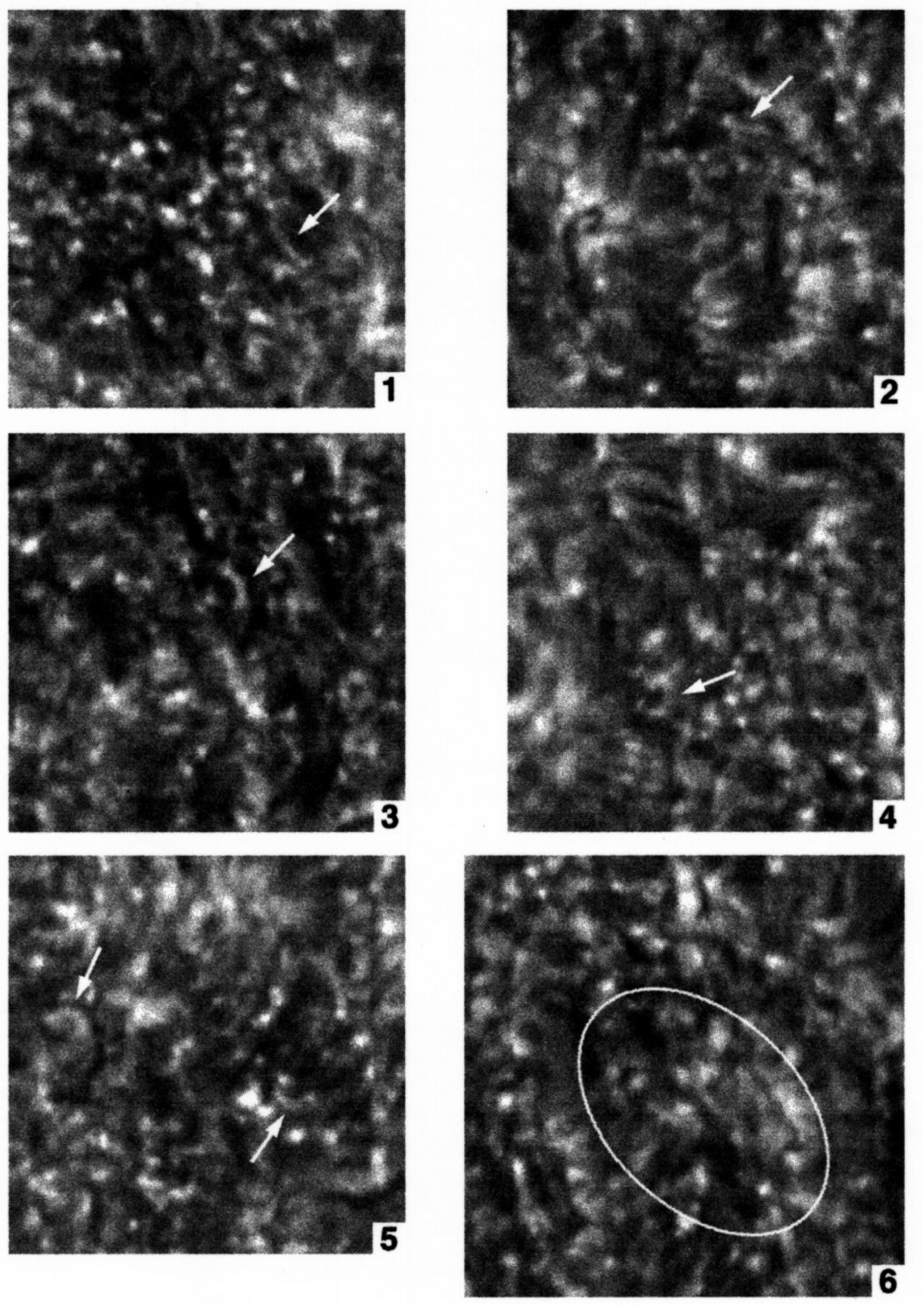

Fig. 3. Reproduction of six regions from the K-line spectroheliogram by Bruce Gillespie. Examples of short fibrils (or loops) connecting adjacent INBPs are indicated by arrows in frames 1, 2, 3, 4 and 5.

brightness) or NBPs (high brightness). We show in Fig. 1 (boxes A & B) examples of these NBPs (low brightness). Bappu & Sivaraman (1971) noticed such emission points in some of the excellent quality Kodaikanal K-line spectroheliograms during the years of deep solar minimum and coined the term “network bright points (low intensity)” to distinguish them from the conventional quiet sun network elements. They also found that these “network bright points (low intensity)” possess the same value of the K$_{2V}$ emission width as the inner network bright points (INBPs). We have measured from the co-aligned K-line SHG - magnetic scan pairs the brightness of all such NBPs and the magnetic fields of the magnetic elements with which they spatially coincide, the same way as we did for the INBPs. In Fig. 4 we present the scatter plot of the brightness vs magnetic field for these NBPs. It can be seen that the fields associated with NBPs are higher than for the INBPs. Our interpretation is that the NBPs (low brightness) are those INBPs (and the corresponding IN magnetic elements too) that had a long lifetime during which the corresponding IN magnetic fields coalesced with consequent increase in K emission. Nindos & Zirin (1998) have provided examples of such events. Originally located in the cell interior, they have been swept towards the cell boundaries during their lifetimes by the radial flows within the cell. According to Martin’s estimates (1990) about 90% of the net-

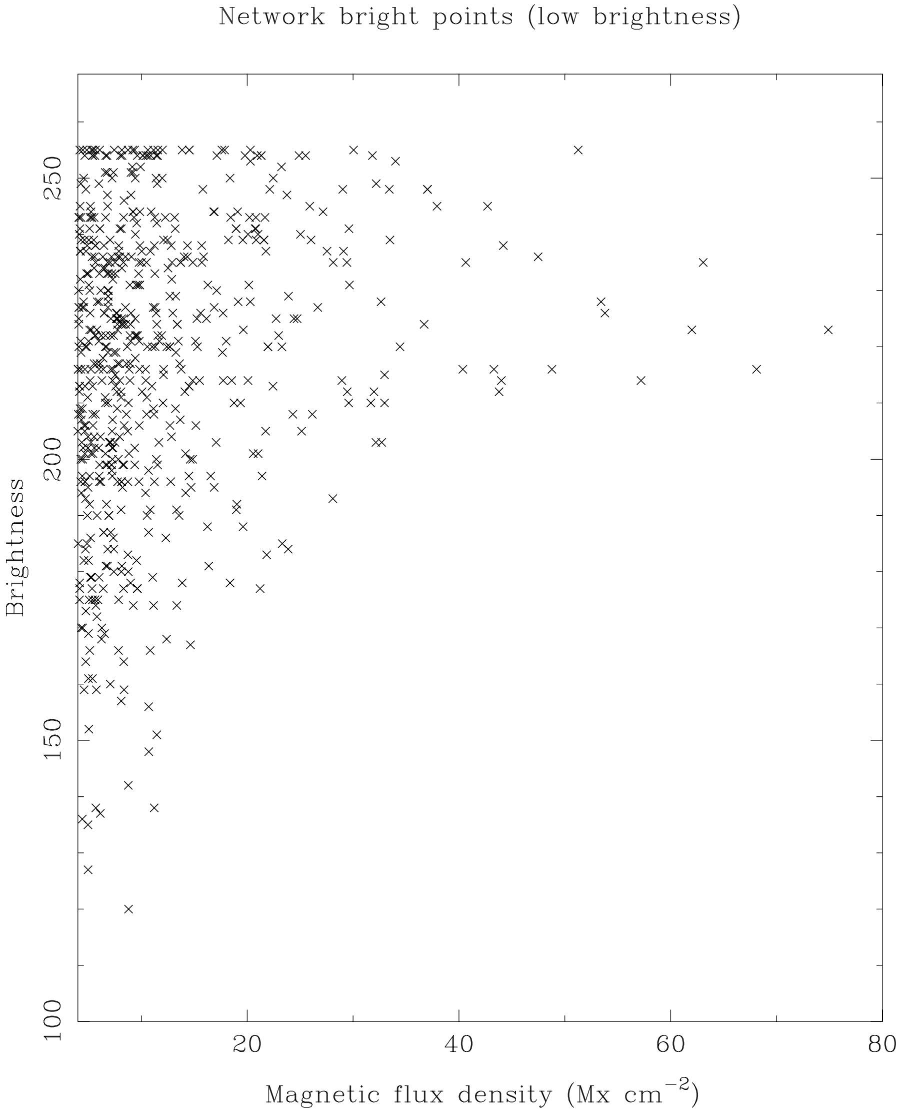

Fig. 4. Scatter plot of the maximum brightness of the NBPs (low brightness) vs. the maximum absolute value of the magnetic field of the cospatial magnetic elements over an area of 2 × 2 pixels. Notice that the fields are higher than for the INBPs of Fig. 2.

work concentrations (mixed polarity network) originate from ephemeral active regions and the rest, 10%, from merged clusters of intranetwork fields. Wang et al. (1995) and Zhang et al. (1998b) have also provided many instances of merging of the IN magnetic elements. In view of this it would be reasonable to infer that the network elements (low brightness) are those INBPs associated with the IN magnetic elements that merged during the time they spent within the network.

5. Network bright points (high brightness)

These structures have two components: the first one is the quiet sun network formed by the complicated statistical processes of frequent collisions and coalescence and rapid replacement of flux from the flux bank provided by the ephemeral active regions described by Martin (1990) and modelled by Schrijver et al. (1997), and the second one consists of the familiar coarse mottles (De Jager, 1959) which are the fragmented remnants from decaying or decayed active regions, patterned and added to the network boundaries by the flows on the solar surface. It is vital to know how far the quiet sun network and the coarse mottles differ in terms of the long-period oscillations exhibited by the "network bright points" (Kalkofen, 1997) or any other observable properties. Also, it might be important to know whether the quiet sun network elements originating from the ephemeral active regions and those from the merger of intranetwork fields (which are also typical features of the quiet sun) have identical or different properties. It would be worthwhile to know how do these properties manifest themselves and how far the brightness - magnetic field relationship for the quiet sun network (cf. Skumanich et al., 1975; Stenflo & Harvey, 1985; Nindos & Zirin, 1998) might apply to these different quiet sun network structures.

6. Conclusions

1. There are 3 classes of INBPs
   (a) those that show excess emission and are associated with enhanced IN magnetic fields > 4 Mx cm^{-2} (these constitute 60% in our study),

  - (b) those that show equal excess emission but are associated with bipoles with flux densities generally ≤ 4 Mx cm^{-2} (these constitute 25% in our study), and
  - (c) those that show weak emission (probably unresolved emission) and seemingly associated with fields < 4 Mx cm^{-2} which is below the noise level set by us for our magnetic scans (these constitute 15% in our study). These are probably the unresolved background fields.

2. In particular, this study suggests that cases of magnetic bipole merging have been discounted in other studies (Nindos & Zirin, 1998; Lites et al., 1999) since these bright points are associated typically with relatively small (and temporally diminishing) net field values. When these cases are also included, it is found that the correlation between bright points and co-located magnetic elements in the data reported here is as high as 85%.
3. Although we have established a spatial correspondence in the locations of the INBPs and IN magnetic elements, we have not been able to obtain a correlation between the brightness of the INBPs and the corresponding IN magnetic elements (if this exists on the sun) because of the scatter caused by the 3-min. oscillations.
4. The results of the present study establish the association of K_{2V} bright points with magnetic elements and, so, confirm the findings of Sivaraman & Livingston (1982) and Nindos & Zirin (1998). The mean field of the IN magnetic elements associated with the INBPs from our measurements is 7.2 Mx cm^{-2} above the noise level. Our observations are with limited spatial resolution as we have averaged the brightness and magnetic field values over a 2×2 pixel area. If the INBPs and IN magnetic elements are sub-arc-sec structures in reality then the flux density of the IN elements as per our measurements could be several hundred Mx cm^{-2}. Such fields would then become dynamically important since the IN elements would serve as sites where the 3-minute waves can be excited (Kalkofen, 1996). Fields of this strength have been measured by Keller et al. (1994) and Lin (1995). Note that one should normally observe significantly more IN magnetic elements than INBPs since INBPs, due to their brightening process (3-minute pulse), could be “dark” at the time the spectroheliogram is recorded. The apparent lack of IN magnetic elements is probably due to the averaging process of the smaller sub-arc-sec unresolved magnetic flux tubes.
5. We have identified instances of short fibril (loop) structures connecting adjacent INBPs from the excellent K spectroheliogram close to the limb obtained by Bruce Gillespie. This is a direct visual evidence of the INBPs’ association with the IN magnetic elements.
6. We are aware that the data we have analysed are not an ideal set of observations to settle this question - association of INBPs with IN magnetic elements (or otherwise) indisputably. But this is the best that can be done with the best facilities that are currently available. What is needed?
   - (a) spectroheliogram time sequence at high cadence (every 5 sec or so) with a narrow spectral band pass as we have used and under excellent seeing conditions, and
   - (b) magnetic scans with better S/N ratio at high cadence and simultaneous with the spectroheliograms.
7. With these data
   - (a) the effect of the 3-min. oscillations can be effectively eliminated,
   - (b) the trajectories of the INBPs and the associated IN magnetic elements can be monitored to see whether they follow identical patterns. Zhang et al. (1998a) have done this for many IN magnetic elements using the BBSO data,
   - (c) the oscillation period of the NBPs (low brightness) can be determined. This would tell us the effect, if any, due to magnetic field coalescing.

Acknowledgements. This research is supported in part by a Grant from the US - INDIA Cooperative Science Program of the International Programs Division of the Smithsonian Institution. Three of us (K.R.S., S.S.G and S.S.H) acknowledge the support provided by the Department of Science and Technology, New Delhi, India and the encouragement provided by Prof. R. Cowsik, Director, Indian Institute of Astrophysics, Bangalore. We wish to express our sincere thanks to Keith Pierce who fabricated the spectroheliograph set up which helped us to acquire two dimemsional images with high spectral purity and to Harry Jones, Frank Recely and Teresa Bippert-Plymate who helped us with the magnetic area scans at the vacuum telescope simutaneous with the SHGs. We are thankful to Ms. Jeannette Barnes and Dave Bell of the NOAO who provided extensive help while reducing the data using the IRAF package, to Mark Hanna of the NOAO who helped us in making the prints of some of the figures and to Baba Vergheese of IIA, Bangalore who helped us with part of the reductions and plots and with the latex format. We are grateful to Jack Harvey, Douglas Rabin, Frank Hill and David Jaksha of the NSO for sparing time for many valuable discussions in the course of the analysis and the preparation of this paper. We are thankful to NSO for permitting us to reproduce sections of Bruce Gillespie′s spectroheliogram in this paper.

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