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Chromospheric spicules and solar corona

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Results of recent observations of chromospheric spicules on the Sun, obtained during the last decades, are briefly reviewed. Data on spicules of different types and their possible counterparts on the solar disk have been collected. Their properties, such as lifetimes, length, thickness, velocities, connection with underlying magnetic field and supposed role in transport of hot plasma and energy into the corona, are considered.Observations with both the ground based telescopes such as Swedish Solar Telescope (SST) on La Palma, New Solar Telescope (NST) at Big Bear, Dunn Solar Telescope (DST) at National Solar Observatory (NSO) and space stations (Hinode, SOHO, TRACE, SDO) are used. Analysis of spectral lines asymmetry reveal weak matter upflows with the velocities of 30–100 km s^{-1}, directed from the chromosphere through the transition region (TR) to the corona. Activity in the corona is distinctly linked with activizing in the chromosphere. Evaluations of the energy, provided by so-called type II spicules, show that the spicules could play a great role in the heating of the corona.

Keywords: Sun, chromosphere, type II spicules, heating of the corona, magnetic reconnection

1 Introduction

Up to now with the best ground-based observations, combined with high resolutions observations from space, there remain many unanswered questions: how energy, generated in the cooler photosphere, is transported into the corona to heat it to temperature of a few millions degrees, and what is the role of the chromosphere, being the interface between photosphere and corona, in these processes.

The chromosphere is a highly dynamic, fine structured and enigmatic phenomenon on the Sun. It is dominated by thin small-scaled, short-lived structures, rapidly evolving with time and height and occurring continuously everywhere: in quiet Sun (QS), in and around active regions (ARs), faculae plages and coronal holes (CHs). These structures are jet-like that look differently in different spectral lines and in dependence from the site where they appear. At and nearby the solar limb they are distinctly seen as bright "straws" or "projections", grouping in "bushes" and stretching like "hedge

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rows" along the boundaries of supergranular cells. They were first discovered and revealed by Secchi (1877) and later named "limb spicules" by Roberts (1945). For a long time, typical spicules were assumed to be a possible candidate to provide the corona with hot mass but no observational relations between spicules dynamic and corona activity have been found. Recently observations from the Hinode in the Ca II H line with excellent temporal and space resolution made it possible to discover so-called type II spicules (De Pontieu et al., 2007a), that appear to be more suitable to make connections between relatively cool chromosphere and hot corona.

Besides limb spicules, some other fine chromosphere structures exist and these are observed on the solar disc and have their terms. So the term mottles is used for rapidly changing "hair-like" short jets visible as dark features in QS regions on the solar disc (Hansteen et al. 2006). Mottles are grouped in rosettes or chains forming complex geometric patterns along the boundaries of supergranular cells. They are well seen in the H_α and Ca II lines. In faculae plages with strong unipolar magnetic field, which is more vertically oriented, dynamic fibrils (DF) are seen. They are short and form a carpet above the photosphere. In ARs there exist also stable low-lying and long-lived fibrils. They are oriented more horizontally and are noticeably longer than DFs (Tsiropoula et al. 2012).

Comparison of properties and behaviors of fine structures which make up the chromosphere demonstrate a similarity of characteristics what permits us to think that some (if not all) of the structures are related or possibly are the same phenomena. Some relations will be discussed by us but the full analysis is impossible because different phenomena are observed with different instruments, with different resolutions and in different spectral lines.

2 Type I and Type II spicules

There exist at least two types of spicules: some living 3–10 minutes and some more dynamic with lifetimes of 10–100 seconds. However Tavabi et al. (2011) have recently stated that spicules are possible to be classified in four types in depending of their diameters, ranging from $0.3''$ to $1.15''$. Insufficient observational data do not allow us to address and decide this problem.

A classical type I spicule with 3–7 minutes lifetime undergoes in its evolution a cycle of upward and subsequent downward motions and has $\sim$ 600 km in diameter and velocity of $\sim$ 20–30 km s^{-1}. By observations in the CaII H line with the SOT on the Hinode, type II spicules show only ascending phase and fade away without a descending phase. Type II spicules are longer and thinner than type I spicules, and live dozens of seconds and rich velocities of 100 and more km s^{-1}.

In spicules, besides ascending and descending motions, also swaying, twisting and torsion motions are also observed, and these make it difficult to identify a separate spicule and trace its evolution. Near the solar limb spicules strongly shield each other. In addition, distortions due the projection effect and spicule inclination give an unreal and misleading picture of spicule dimension and behavior.

Zhang et al. (2012) reviving the same data, that were used by De Pontieu et al. (2007a), identified 10^5 spicules in the quiet Sun (QS) and 10^2 inside coronal holes (CH). No convincing type II spicule has been found. More than 60 % of the identified

spicules both in the QS and CHs show a complete cycle of upward and subsequent downward motions, only upward motion demonstrated by ∼9 % in the QS and ∼24 % in the CHs. The other cases show only descending phase or were uncertain. That is why Zhang et al. (2012) concluded that the supposition of coronal heating by type II spicules should be taken cautiously. Later the conclusions by Zhang et al. (2012) were analyzed in detail in several publications (Pereira et al. 2012; Martinez-Sykora et al. 2012;). Zhang et al. (2012) mislabeled AR data set as QS. Besides, observed in CHs up- and down motions were not real, because a careful consideration and examination reveal that both visual inspection and automated tracking show only upward motions. Pereira et al.(2012) also indicated other mistakes by Zhang et al. (2012), whose results seem to be due to mistakes in tracking of spicules and effects of insufficient spatio-temporal resolution that do not allow us to determine real spicules properties and recognize another than usual type spicules. Pereira et al. (2012) confirmed the results on type II type spicules, presented by De Pontieu et al. (2007a). They showed, in contradiction to Zhang et al. (2012), that the type II spicules really exist, demonstrating only upward motions, rapidly fading after reaching maximal heights and having shorter lifetimes and greater velocities.

Now most of scientists have no doubt of the existence of type II spicules but their role in heating of the solar corona is not quite clear. Interface Region Imaging Spectrograph (IRIS), recently launched by NASA (De Pontieu et al. 2014), has given a new possibility to observe evolution of type II spicules. The observations from the IRIS confirm that fading of the Ca II H spicules seem to be caused by rapid heating to higher temperatures. In the initial stage the type II spicules are seen in the Ca II H line but, heating, they become invisible in Ca II line. Such possible cause was considered earlier in (De Pontieu et al. 2007a; 2009; 2011; McIntosh and De Pontieu 2009; McIntosh et al. 2010; Tian et al. 2011).

Images of spicules are shown in Fig. 1. In the first row on the left side type I spicules in DOT (Dutch Optical Telescope) Ca II image, taken in 2003 November 4 in AR near the solar limb, are seen (by Fig. 1 from Tziotziou 2005). Dark elongated areas near the limb are solar spots. Besides spicules and fibrils a large narrow surge is seen.

The SOT Ca II H 396.8 nm filter is wide (2.2 Å), and disc images contain significant contribution from the photosphere emission. A visual inspection of the behavior of spicules near the solar limb, where the contributions from the middle and upper chromosphere is dominating, reveals spicules with at least two time scales: long-lived slowly evolving type I spicules and short-lived dynamic type II ones. The Fourier filter with the high frequency passband ($\geq$ 15 mHz) was used to isolate the type II spicules. In the middle of the first row Hinode Ca II H unfiltered image is shown and on the right the filtered image reveals distinctly seen type II spicules, associated with the transition region, seen on the TRACE in the C IV line (T$\sim 10^5$) which one can see, comparing images presented in Fig. 2 in (De Pontieu et al., 2007b). In the middle row on the left the AR NOAA 10813 on 2005 October 4 (S 7°, E 37°) observed in the H_α line with the SST on La Palma, is shown. The positive and negative magnetic fields are outlined by the white and black contours respectively. The H_α dynamic fibrils (DFs) are in the unipolar region between two spots (for $x = 35''$–$60''$ and $y = 20''$–$40''$) and their temporal evolution is shown on the right of the middle row. DFs are thin and dynamic.

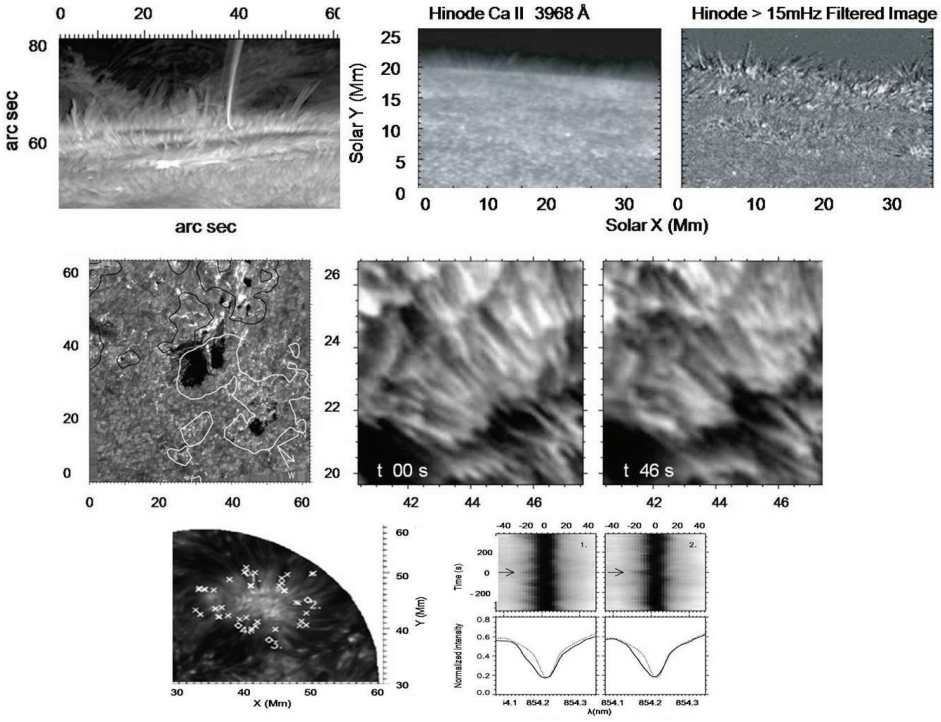


Figure 1 Spicules near the solar limb and their disc counterparts DFs and RBEs.

In the bottom row on the left a rosette structure, seen in the field of view (FOV) of IBIS (Interferometric BIdimensional Spectrometer) at the DST of the NSO near the solar disc center, is shown (by Fig. 1 from Langangen et al., 2008a). The center of the rosette is covered by mottles (see Langangen et al., 2008b). The positions of the rapid blueshifted excursions RBEs at the edges of the rosette are marked by the crosses. On the right the temporal evolution of the RBE1 and RBE2, observed in the Ca II 854.2 nm and indicated by the diamonds on the image of the rosette, and the RBE spectra are shown. For the comparison the averaged Ca II 854.2 nm profiles are presented by the dotted lines (by Fig. 2 from Langangen et al., 2008a).

Data on some parameters of spicules, collected by us from published scientific papers, are given in Table 1. There are given lifetimes, appearing the magnetic field-aligned velocities (because both the limb spicules and their disc counterparts follow magnetic field lines), temperatures, appearing lengths and widths. The parameters of spicule counterparts on the solar disc, that will be discussed lower, are presented too.

Table 1 Different types of limb spicules and their disc counterparts.

Event	Life-time	V, km s^{-1}	$T\times10^{-5}$, K	Length, Mm	Width, Mm	Instru-ment	Reference
Type I spicules	300–600	< 25	0.15–0.17	4–10			Muravski, 2011
	180–600	20–30	0.05–0.5	4.2–12.2		Hinode	De Pontieu, 2009
	180–720	3–75	2.0–9.0			SST	Passachoff, 2009
	180–600	10–30				Hinode	De Pontieu, 2012
	180–420	10–40		10	0.7		Steiner, 2014
Mostly in ARs	100–500	10–50					De Pontieu, 2012
Dynamic fibrils	180–900	10–30		5–9	2–1	SST	De Pontieu, 2007b
Type II spicules	10–100	50–150	100–2000		0.1–0.3	Hinode	De Pontieu, 2007a
	50–100	30–110				Hinide	Pereira, 2012
	10–60	40–200		< 5	$<$ resol.		Steiner, 2014
	500–800	80	0.1–0.8	16–20		IRIS	Pereira, 2014
	800		1.0	22		AIA	Pereira, 2014
QS, CH	20–100	30–100					De Pontieu, 2012
RBEs	< 60	15–20		0.5–1.5	0.3–0.6	IBIS DST	Langangen, 2008
RBE, CH	84	up to 50				SST	Sekse et al., 2012
RBE, disk	5–60	15–40				SST	Sekse et al., 2013a
Spicules in QS	148	15.5				Hinide	Zang et al., 2012
Spicules in CHs	148	15.5				Hinide	Zang et al., 2012

3 Corona and type II spicules

We can consider that Hara et al. (2008) were the first to reveal a weak asymmetry in blue wings of the coronal Fe XIV 274 Å lines which might be a response of the corona to type II spicules activity, providing low corona by hot plasma and energy. Later more distinct evidences were found (De Pontieu et al. 2009).

Hara et al. (2008) analyzed observations of the AR NOAA 10938, obtained with the EIS/Hinode on 2007 January 18 and 24 near the disc center and west limb correspondingly. In the center of the solar disc profiles of the Fe XIV 274 Å line, registered in the vicinity of the footpoints of the AR loops, show blueshifted asymmetries being some evidence of plasma flows with the upward flow velocities of tens km s^{-1}. When the AR reached the west limb the velocities, determined by the blue wing excess, became noticeably less. The result is possible to explain by the scheme proposed in (De Pontieu et al. 2009). Upward velocities in type II spicules, being taller and oriented more vertically than the type I spicules, are better to observe near the center of the solar disc. At the limb line-of-sight velocity component of upward motion is less.

To find a response of the corona to the activity of the chromospheric spicules De Pontieu et al. (2009) investigated the ARs NOAA 10976 and 10977, situated in 2007 December 2 and 5 near the center of the solar disc. The observations with the Hinode/SOT and EIS in the Ca II H line and EUV Fe XIV 274 Å coronal lines were fulfilled simultaneously. The EIS spectra were analyzed in the sites with the morphology typical for cooler chromospheric structures, named "moss", that were located in the vicinity of the footpoints of hot coronal loops. With reference to

Hansteen et al. (2007) blueshifted centers of coronal lines show typical velocities of 10–20 km s^{-1}, not correlated with the activity in the upper chromosphere (UCA). To minimize the effect of the bright cores of the coronal lines De Pontieu et al. (2009) calculated maps of blue-red (B-R) asymmetry in the coronal Fe XIV 274 Å line (T $2 \cdot 10^6$K) and compared them with the images obtained on TRACE in the 171 Å line (T $8.0 \cdot 10^5$ K). They revealed that upward motions generally arose in moss sites of the TR located in the vicinity of the coronal footpoints. It is seen in Fig. 2 (by Fig. 1 from De Pontieu et al. 2009) where appearance of the AR NOAA 10977 on 2007 December 5, profile of the Fe XIV 274 Å line and B-R map are shown.

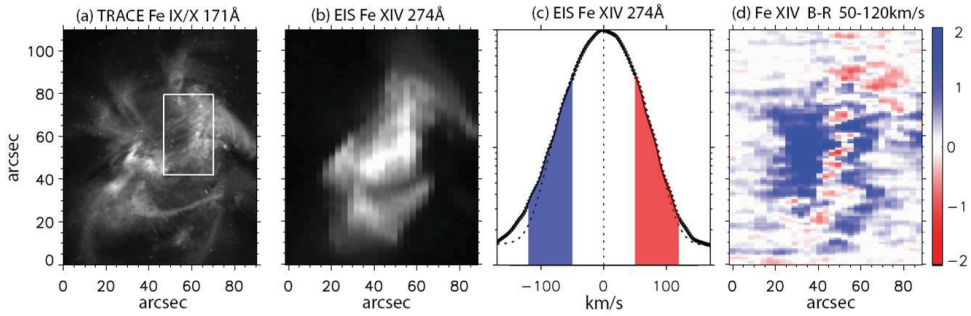


Figure 2 NOAA10977 on 2007 December 5: (a) moss regions in 171 by TRACE, (b) hot coronal loops in Fe XIV 274 by EIS Hinode, (c) asymmetry of the 274 line due upward flows of hot plasma, intensities are plotted in the logarithmic scale, (d) a map of the B-R asymmetry for the line wings corresponding to the velocities ranged from 50 to 120 km s^{-1}; the logarithmic scale is used for the velocities, (from De Pontieu et al. 2009).

The images of the chromospere in the Ca II H line, obtained with the wide band-pass (2.2 Å) SOT filter, contain mainly information on slowly evolving photosphere and low chromosphere emission. UCA maps were calculated using temporal high-pass Fourier filtering, knowing highly dynamic nature of the UCA events with time scales $< 60^s$.

In De Pontieu et al. (2009) it is shown that high velocities in the corona are associated temporally and spatially with increase of the activity at chromospheric heights, observed in the Ca II H line and do not correlate with the intensity in the corona corresponding the temperature about 2 MK. In Fig. 2 (De Pontieu et al. 2009) for the NOAA 10977 on 2007 December 2 there are strips with dimension of $\sim 5'' \times 65''$ which show intensity in the 274 Å line (a), the B-R asymmetry in the 274Å line in the wings corresponding to velocities of 120 km s^{-1} and 80 km s^{-1} respectively (b, c), the map of the activity in the upper chromosphere (d), calculated on the base of the observation of a plage area in the Ca II line, presented in (e). One can see that the places with high velocities in the corona (b, c) correlate well with the sites of the increased intensity in the upper chromosphere (d) and do not correlate with the intensity in the corona (a). Observations in the UV C IV 1548Å and Ne VIII 770 lines with the SUMER SOHO also provide evidence of weak upward flows with high velocities of 50–120 km s^{-1}. The flows go through the chromosphere, transition

region (TR) and lower corona passing through the layers of the solar atmosphere with temperatures widely ranged from 10^4 K to $6{\cdot}10^5$ K. The upward flows are ubiquitous, arising continuously in ARs plages, in the vicinity of chromospheric net boundaries in QS and CHs. Comparing the upward velocities in chromospheric type II spicules, found in (De Pontieu et al. 2007a) from Ca II H observations at the limb and upward velocities, derived from B-R asymmetry of the Fe XIV 264Å and Fe XIV 274 Å lines for moss regions near the footpoints of large coronal loops in NOAA 10977 on 2007 December 5 De Pontieu et al. (2009) show that ranges of chromospheric and coronal velocities are similar. The result is additional evidence to support the proposal that a part of heating and energizing of the corona arises at the chromosphere and is transported into the corona by type II spicules (see Fig. 3 in De Pontieu et al. 2009).

4 IRIS observations of the type II spicules

IRIS is a NASA Small Explorer mission. Disappearance of type II spicules because of possible heating to higher chromospheric, TR or even coronal temperatures was difficult to study and establish using evidence to support the proposal that previous instruments with insufficient spatial and temporal resolution. The IRIS is ideal to observe the interface between the chromosphere and corona, and type II spicules that are very dynamic and fine structured. Pereira et al. (2014) analyzed dynamics and thermal of evolution of the quiet Sun spicules, using observations from the IRIS, and comparing them with the Ca II H spicules from Hinode/SOT and their higher temperature counterparts from the Atmospheric Imaging Assembly (AIA)/SDO.

The IRIS filtergrams of the quiet Sun at the south pole were obtained on 2014 February 21 at 279.6 nm (Mg II, 10^4 K) and 140.0 nm (Si IV, $8{\cdot}10^4$ K), taken with a 19 s cadence. From the SOT/Hinode the 396.85 nm filtergrams (Ca II H, $9{\cdot}10^3$ K) were taken with a 4.8 s cadence and from AIA/SDO the 30.4 nm filtergrams (He II, 10^5 K), taken with a 12 s cadence, were used. Additionally, observations at the solar north pole on 2013 October 9 were analyzed.

Comparing the IRIS, SOT and AIA filtergrams it is possible to see that the Mg II k spicules are seen as a natural upward extension of the Ca II H spicules. They are taller than the Ca II H spicules and the Si IV spicules look like a continuation of the Mg II spicules and expand even higher. The He II 30.4 nm spicules extend just above the Si IV spicules and their shape is blurrier, partly because of the lower spatial resolution. Many of the Si IV spicules have the brighter top and brighter bottom parts (Fig. 3 by Fig. 1 from Pereira et al. 2014).

The observed spicules were generally of type II. They show a fast rise with the velocities greater than 50 km s^{-1} and subsequent fading from the Ca II H filtergrams. In the IRIS filtergrams they have a similar upward velocity but continue to rise after they fade in Ca II and reach heights up to 20 Mm and often fall down later. Fading in the Ca II H line the type II spicules continue to evolve in the hotter lines (Fig. 4 by Fig. 3 from Pereira et al. 2014). This extended evolution leads to longer spicule lifetimes in the IRIS images, typically 500–800 s. The presence of spicules in multiple filters underscores their multithermal nature. The results confirm the conclusion by De Pontieu et al. (2007a) on the reality of the type II spicules.

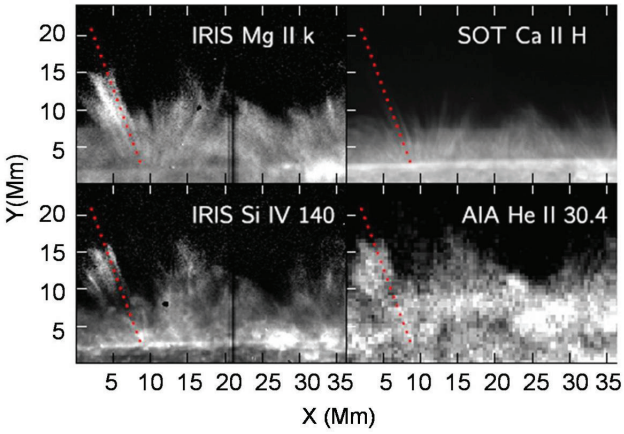


Figure 3 Comparison between the IRIS Mg II k and Si IV 140 nm, SOT/Hinode Ca II H and AIA/SDO He II 30.4 nm filtergrams on 2014 February 21 (by Fig. 1 from Pereira et al. 2014). The dotted line is the spicule axis that is used for building the spacetime intensity diagrams for spicule A (see Fig. 4).

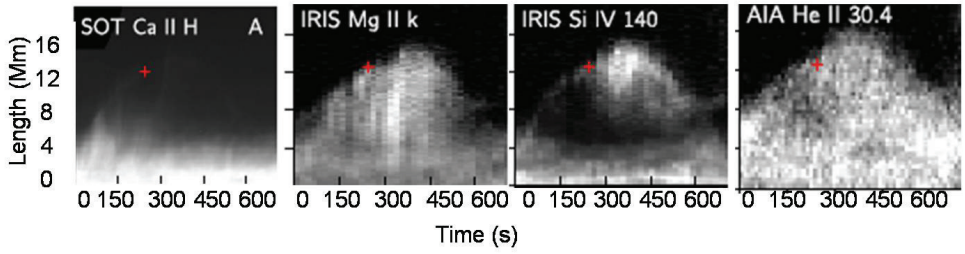


Figure 4 Spacetime diagram for the intensity along the axis of the QS spicule observed on 2014 February 21 in different spectral lines, by Fig. 3 from Pereira et al. (2014).

5 Disc counterparts of the type II spicules

Type II spicules are difficult to observe because of their dynamics, short lifetimes, superposition of spicules along the line of sight, when seen near the limb, and insufficient spatio-temporal resolution. Therefore discovery of rapidly evolving chromospheric events visible at the solar disc and by their properties (rapid apparent upward motions, lifetimes of several dozens of seconds, extensions) being similar to type II limb spicules has evoked a special interest. The events occurred in and around network suggest an association with type II spicules and were possible to consider as disc counterparts of limb spicules. Firstly events with excursions of the absorption in blue wings of line profiles (Rapid Blueshifted Exursions RBEs) were found. Later events with red excursions have been revealed.

Langangen et al. (2008) used the observations in the Ca II 854.2 nm line, obtained on 2004 June 2 during 55 minutes of good or excellent observation conditions with

the Interferometric BIdimensional Spectrometer (IBIS) at the DST of the NSO. Four rosette structures, associated with the sites of magnetic field concentrations, were seen in the field of view (FOV), and 87 rapidly evolving events, with life times less than 60 seconds, lengths of 500–1500 km, widths of 300–600 km, were found, locating near network and having blue asymmetry in the profiles of the Ca II 854.2 nm line. The corresponding line of sight velocities (15–30 km s^{-1}) appeared less than upward velocities in type II limb spicules. Numerical simulations show that for the observed events the visibility is limited by a projection effect and reduced opacity in plasma transported upward.

Similarity in properties and evolution of these events and type limb spicules (upward motions, sudden disappearance, short lifetime, dimensions, localizing at the edges of rosettes) allow us to suggest a link between the events on the solar disc and limb and consider the RBEs as the disc counterparts of type II spicules. A little later Rouppe van der Voort et al. (2009) confirmed the association of RBEs to type II spicules basing on high quality H_α and Ca II 8542 Å observations with the CRISP at the SST/La Palma. A large number of RBEs was found and their properties such as lifetimes, velocities, and lengths appeared similar to the properties typical to the type II spicules. Swaying motions and divergent propagation away from magnetic field concentrations were additional indications that RBEs are the disk counterpart of type II spicules.

Sekse et al.(2012) used observations, obtained in 2010 June 27 in a CH simultaneously in the Ca II 8542 Å and H_α with the CRISP/SST on La Palma. The CH was located at the solar coordinates –70″, 508″ ($\mu = 0.84$). Studying numerous RBEs, they found that their lifetime was about 84 s, magnetic field aligned velocity up to 50 km s^{-1}, transverse velocity ranged from 5 to 10 km s^{-1}. The H_α RBEs were seen to be continuations of the Ca II 8542 Å RBEs. Later Sekse et al. (2013a), based on observations of 2011 with the CRISP/SST on La Palma found for RBEs in the center of the solar disc, propagation away from the magnetic field concentrations with velocities, of 15–40 km s^{-1}, lifetimes of 5–60 s, transverse velocities up to 55 km s^{-1}. The Ca II 8542 Å RBEs were located closer to the rosette centers and appeared earlier than the H_α RBEs. Further Sekse et al. (2013b) analyzed simultaneous observations of the areas in the solar disc, obtained in the H_α and Ca II 8542 Å lines with the SST on La Palma. Five data sets registered in the period from 2008 to 2012 were used. Rapidly evolving events seen in redwings of the lines (Rapid Red Excursions – RREs) were similar to RBEs and have similar lengths, widths, life-times, magnetic field aligned flows, occurring everywhere on the solar disk in the same places where RBEs were and at the same time. Both are touching each other. Such similarity implies that RBEs and RREs are displaying the same phenomena.

According to the analysis by Sekse et al. (2013b), RREs are less abundant and the ratio RREs/RBEs is about 0.52 for the center of the solar disc and about 0.74 near the limb. Both RBEs and RREs demonstrate torsion movements. In Fig. 5 images of simultaneous events and corresponding line profiles are shown.

With reference to Sekse et al. (2013b) most of RREs and RBEs are observed separately as individual events. However many cases have been found when RREs and RBEs seem to be located parallel, touching each other and composing single whole, being parts of the same spicule.The existence of such pairs is possible to explain if it is proposed that Doppler shifts vary along the widths of the RRE and RBE, due

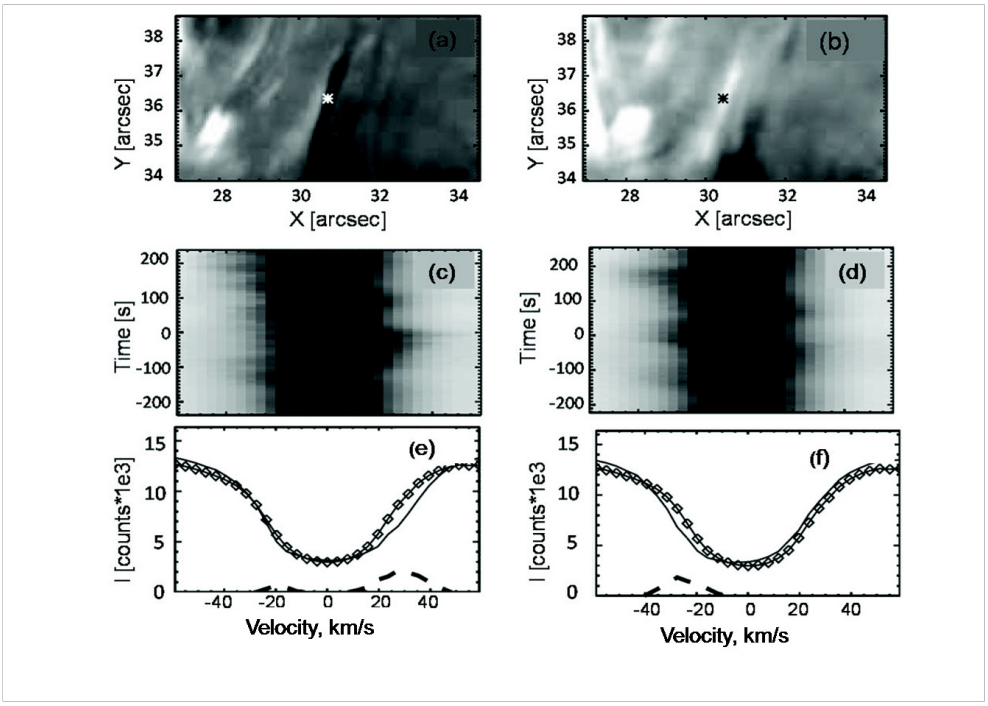


Figure 5 Observations of rapid events in red and blue wings of the Hα line in QS near center of the solar disc. (a, b) Doppler images (35 km s^{-1}) of RRE (dark) and RBE (bright); (c, d) evolution of the RRE and RBE in the place, marked by white and black asterisks correspondingly in the (a, b); (e, f) observed profile, average across the FOV and difference between them for the RRE and RBE middle time moment (from Sekse et al. (2013b)).

torsion motions. In Fig. 5 (by Fig. 1 from Sekse et al. 2013b), evolution with time, followed during more than 400 seconds in the H_α line in QS, is shown.

6 Asymmetry of coronal lines by ground based observations

For a long time, observations on the ground obtained during total solar eclipses, confirmed that profiles of the coronal lines were known to have wider wings than Doppler profiles. Emission excess in blue wings was found by Delone and Makarova (1969) during the total eclipse in 1965 and later data of observations of several solar eclipses were reviewed confirming the existence of multicomponent line profile (Delone et al. 1982).The observations were fulfilled at the installation with the Fabri-Perot interferometer for the green 5303 Å line created in the Sternberg Astronomical Institute (Russia). Our recent analysis of the data on the solar eclipse on 1965 has shown that blueshifted velocities have prevailed (Porfirieva et al. 2013). Tyagun (2009, 2010) revised data sets of about 5500 profiles of the 6374 Å coronal line using observations

at the Large Coronograph at the Sayanskaya Observatory (Russia), obtained from 1968 to 1972. She found that 80 % of profiles of the red coronal line were asymmetric and evaluated that among them the composition of the profiles with the blue and red asymmetry were 52 % and 28 % correspondingly. Profiles asymmetry shows a dependence on solar activity.

Blue and red asymmetry for the green coronal line was also found by Raju et al. (2011), and Prabhakar et al. (2013). They used observations with Fabri-Perot interferometers during total solar eclipses. In Raju et al. (2011) profiles of green Fe XIV 5303 Å line obtained from Fabry-Perot interferometric observations of the solar corona during the total solar eclipse of 2001 June 21 from Lusaka, Zambia were analyzed. About 300 line profiles were obtained within a radial range of 1.0–1.5 $R_\odot$ and position angles between 240° and 280°. Measuring line asymmetry they revealed blueshifted components with Doppler velocity in the range of 20–40 km s^{-1}, increasing toward the solar poles. Possible explanations of this consist in upward quick flows in the type II spicules that were recently found to be important in coronal heating or the nascent solar wind flow.

During the total solar eclipse on 2001 June 21 in Zambia, Prabhakar et al. (2013) found that line-of-sight velocities, determined by blue and red wings, were 30.1 km s^{-1} and 23.6 km s^{-1} correspondingly. The authors believed that such difference was possible to explain by upflows in the type II spicules.

7 Discussion

The type II spicules are thought to play an important role in the transport of hot plasma and energy into the corona. They are the main elements which make up the solar chromosphere which is highly dynamical and extends for 1000 km and higher into the corona. Occurring in chromosphere, they seem to become heated to higher than chromospheric temperatures. Rapid heating is confirmed by some observed facts, such as a rapid fading or on the contrary by sudden increase in emission. Besides upflows with the velocities up to 100–150 km s^{-1}, aligned along the magnetic field, transverse motions with the velocity to 60 km s^{-1} and deviations aside to 1 Mm and torsion motions are observed. Swaying of spicules suggests propagation of Alfven waves. Inclined spectra, observed in spicules, indicate red/blue shift pattern across spicule compatible with strong torsion motion of 20–30 km s^{-1}.

The IRIS observations for the first time gave a possibility to follow the evolution of type II spicules and finally confirmed that the fading of the Ca II H spicules is caused by rapid heating to higher temperatures. By the results obtained from the IRIS the type II spicules really do not fade but continue to evolve, reaching higher distances in the corona and, after cooling, falling back down after 500–800 s. The Ca II H type II spicules are only the initial stages of the events which became invisible in Ca II H filtergrams at higher temperatures. By their properties these energetic type II spicules differ strongly from the type I spicules, which have lower velocities and are visible in chromospheric passbands during all periods of life.

Energy of a single spicule of 10^{23} erg is comparable with the energy of nanoflare. Observations at the Hinode give a possibility to evaluate total number of type II spicules on the solar surface at every moment and total energy, transported by them

upward (of order 10^6 erg cm^{-2} s^{-1}. De Pontieu et al. (2007a, 2009) believe that this energy is enough to heat the corona and cause solar wind. Moore et al. (2011) consider a scenario, suggesting that type II spicules arise as a result of emergence of granule-size bipolar (EBs) magnetic fields in intra granular lanes and subsequent reconnection between them and surrounding magnetic field. The process of reconnection has an explosive nature and is accompanied by propagation of Alfven waves. The total energy, taking into account both the potential and kinetic energy fluxes of type II spicules and energy of Alfven waves generated by EBs, is determined to be about $7{\cdot}10^5$ erg cm^{-2} s^{-1} that is comparable with the estimations reported of other scientists for the energy needed to heat the corona and power the solar wind.

In De Pontieu et al. (2012) observations in the Ca II line are compared with Monte Carlo simulations, considering field aligned flows with the velocities V_p of the order of 50–100 km s^{-1}, torsional and swaying motions with the velocities V_t of the order of 25–30 km s^{-1} and V_s of the order of 15–20 km s^{-1} respectively. The best agreement suggests values of velocities to be $V_p = 60$ km s^{-1}, $V_t = 30$ km s^{-1} and $V_s = 15$ km s^{-1} with periods of 100–300 km s^{-1}. The evidence was found that both swaying and torsional motions are signature of Alfvenic waves with the velocities of several hundred km s^{-1} energy which might be twice as larger as than it was suggested earlier basing only on spicules swaying motions. So type II spicules may play a great role in transporting the energy into corona and organizing solar wind. The conclusion is confirmed by new data from the IRIS (Pereira et al. 2014).

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