object?) determines the relative differential hemispheric activation[4].

Shaywitz and his colleagues[5] asked their subjects (19 males and 19 females) to map the given letter strings onto phonological representations. In other words, the subjects are to determine if two nonsenseword strings rhymed. The test involves phoneme coding. Neural activation during rhyming in males was lateralized predominantly to the left inferior frontal regions (mean number of pixels activated were 11.7 and 5.0 for the left hemisphere and the right hemisphere respectively). In contrast, activation during this same task in females engaged this region bilaterally (mean number of corresponding number of pixels activated for females were 9.4 and 12 in the left hemisphere and the right hemisphere respectively). Shaywitz and his associates thus demonstrated that in a site uniquely serving phonological processing, inferior frontal gyrus (IFG), females devote greater right hemispheric resources to the task. Also, cumulatively larger areas in IFG in both the hemispheres are seen activated in females when compared to males.

However, Fink and his associates in their experiments apparently used only male subjects. Will the results from the female subjects be different in any manner for global/local processing of letter-based and object-based stimuli? In other words, who among the males and females are more likely to 'miss the wood for the trees'? Does Shaywitz *et al.*'s work indicate a natural flair for lullaby among females? I am sure the evolutionists among the biologists are sure to hijack the answers to these and similar questions (as and when available) to see in the answers some biological advantage to the *Homo sapiens* as a species! In the meantime, can we not think of enlarging the scope of our endeavours in brain research so as to find applications in as broad a realm as education, besides the efforts directed towards the amelioration of disorders/diseases afflicting the brain[6]?

1. Springer, S. P. and Deutsch, D., *Left Brain, Right Brain*, W. H. Freeman, New York, 1983, 4th ed.
2. Albert, S. M., *Science*, 1997, **275**, 1547.
3. Fink, G. R., Halligan, P. W., Marshall, J. C., Frith, C. D., Frackowiak, R. S. J. and Dolan, R. J., *Nature*, 1996, **382**, 626–628.
4. Fink, G. R., Marshall, J. C., Halligan, P. W., Frith, C. D., Frackowiak, R. S. J. and Dolan, R. J., *Proc. R. Soc. London*, 1997, **B264**, 487–494.
5. Shaywitz, B. A., Shaywitz, S. E., Pugh, K. R., Todd Constable, R., Skudlarskl, P., Fulbright, R. K., Bronen, R. A., Fletcher, J. M., Shankweller, D. P., Katz, L. and Gore, J. C., *Nature*, 1995, **373**, 607–609.
6. Ramakrishna, T., *Curr. Sci.*, 1997, **73**, 1045–1047.

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Magnetic reconnection on the Sun: Ultraviolet observations of bi-directional plasma jets

B. N. Dwivedi and Anita Mohan

Magnetic field reconnection transcends the traditional disciplines of laboratory, space and cosmic plasma physics. The process is known to occur in fusion devices such as tokamaks where it causes major disruption of the plasma confinement. It is thought to occur in solar flares and in other energetic events on the Sun. It takes place at planetary magnetopauses, and in planetary, as well as cometary, magnetic tails. Reconnection also plays an important role in other cosmic objects such as accretion discs, and in a variety of current sheets occurring in interplanetary, interstellar, and intergalactic space. Detailed study of reconnection processes in the laboratory, in computer simulations, in the Earth's magnetosphere and in the solar plasma is, therefore, in the forefront of current researches.

In cosmic plasmas, large scale lengths L, large velocities V, and small electrical resistivities η combine to form large values of the magnetic Reynolds number $R_m = \mu_0 VL/\eta$, a condition in which the plasma and magnetic fields are tightly coupled or 'frozen' together. If the ratio of plasma to magnetic energy density is large, non-uniform motions in such plasmas often stretch magnetic loops or push differentally magnetized regions together into configurations, where magnetic field exhibits large shear, i.e. it changes direction and magnitude rapidly across a narrow electric current sheet. If the ratio is small, the magnetic field organizes the plasma motion instead. And the currents have a tendency to flow along magnetic field lines, a situation that also leads to sheared magnetic fields. All such field configurations contain free magnetic energy. Magnetic reconnection provides a means of converting some or all of this energy to plasma kinetic and thermal energy and thus of changing the field configuration into a thermal equilibrium.

Magnetic reconnection is the process by which magnetic lines of force break and rejoin into a lower-energy configuration. This is considered to be the fundamental process by which magnetic energy is converted into plasma kinetic energy. The Sun has a large reservoir of magnetic energy. The energy released by magnetic reconnection has been invoked to explain both large-scale events, such as solar flares and coronal mass ejections, and small-scale phenomena, such as the coronal and chromospheric microflares that are likely candidates to heat and accelerate the solar wind.

The solar network (chromospheric and photospheric features arranged in a cel-

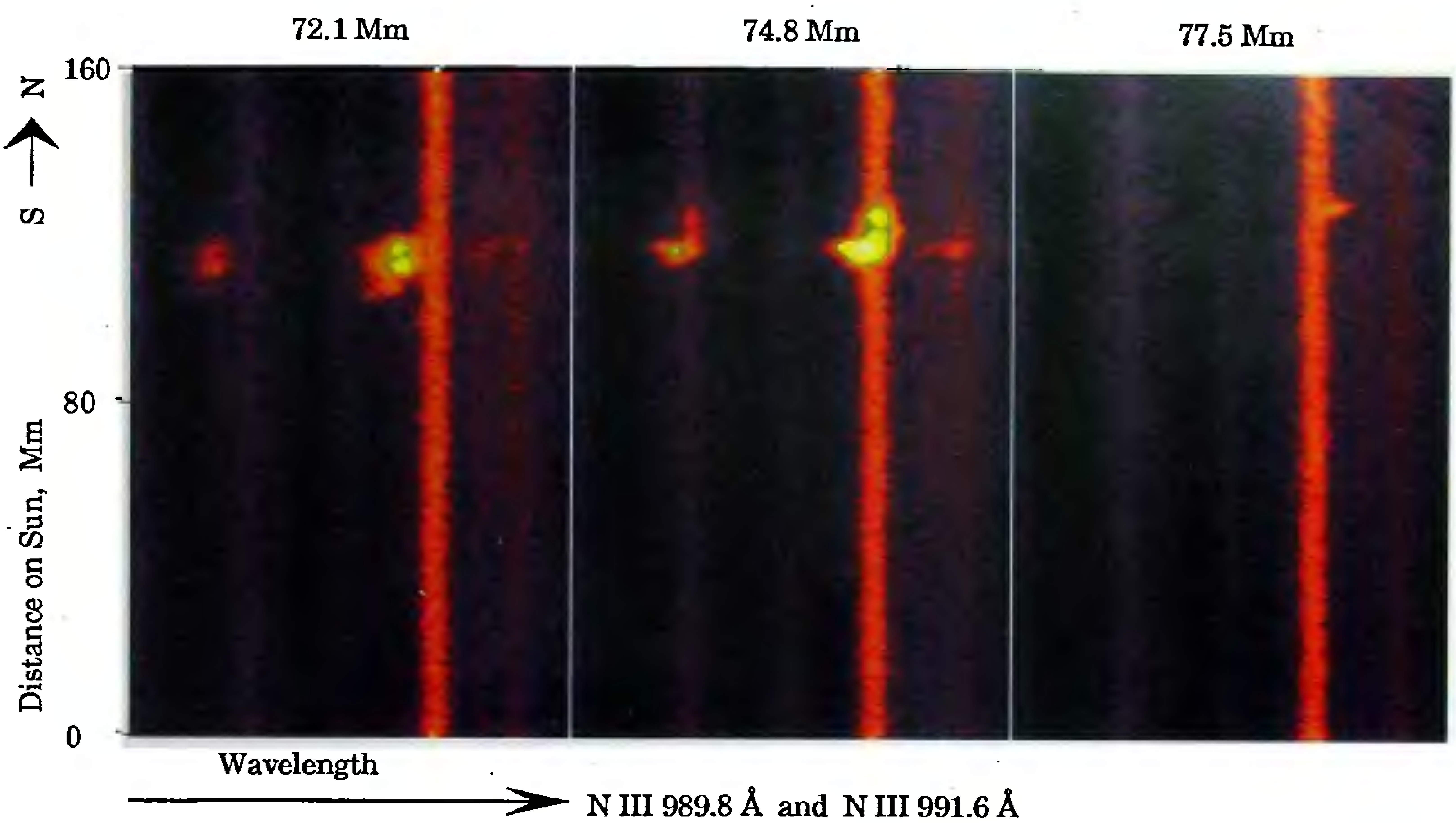

Figure 1. N III lines observed at three consecutive raster positions at 72.1, 74.8 and 77.5 Mm, respectively, above the limb showing the signature of a violent dynamic event with Doppler velocities from – 170 km/s to 100 km/s. It is to be noted that the emissions outside the event purely come from scattered light of the N III lines from the solar disc indicating wavelengths at rest.

lular structure, associated with supergranular cells and magnetic field) is the pattern of supergranulation (a convection pattern consisting of large, 30,000 km diameter, cells in which flow is mostly horizontal and outward from cell centres but which has weak upward flow at cell centres and downward flow at cell boundaries) cells seen over the entire solar surface. The cell boundaries, along which the magnetic field concentrates, are in a state of continuous variability and violent activity. Sudden small-scale plasma jets, microflares, and explosive events are examples of this activity. Space observations from Skylab, SMM (Solar Maximum Mission) and HRTS (High-Resolution Telescope and Spectrograph) provided extremely valuable data for systematic studies of the reconnection process on the Sun. But the observational evidence for reconnection remains largely indirect. They are based on observation of variations in the solar ultraviolet and X-ray morphology; and sudden changes in the magnetic topology, and the apparent

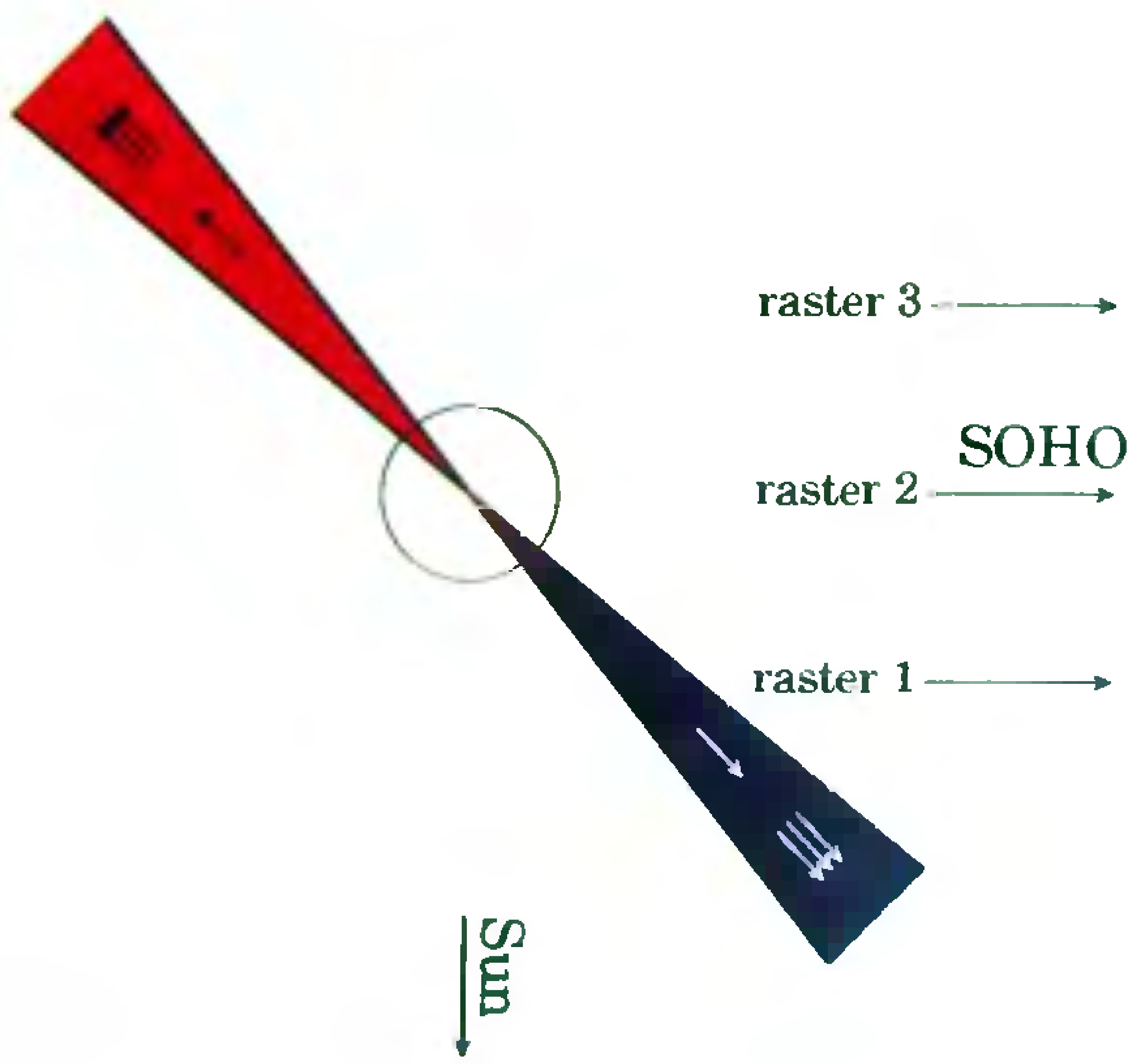

Figure 2. The observational geometry.

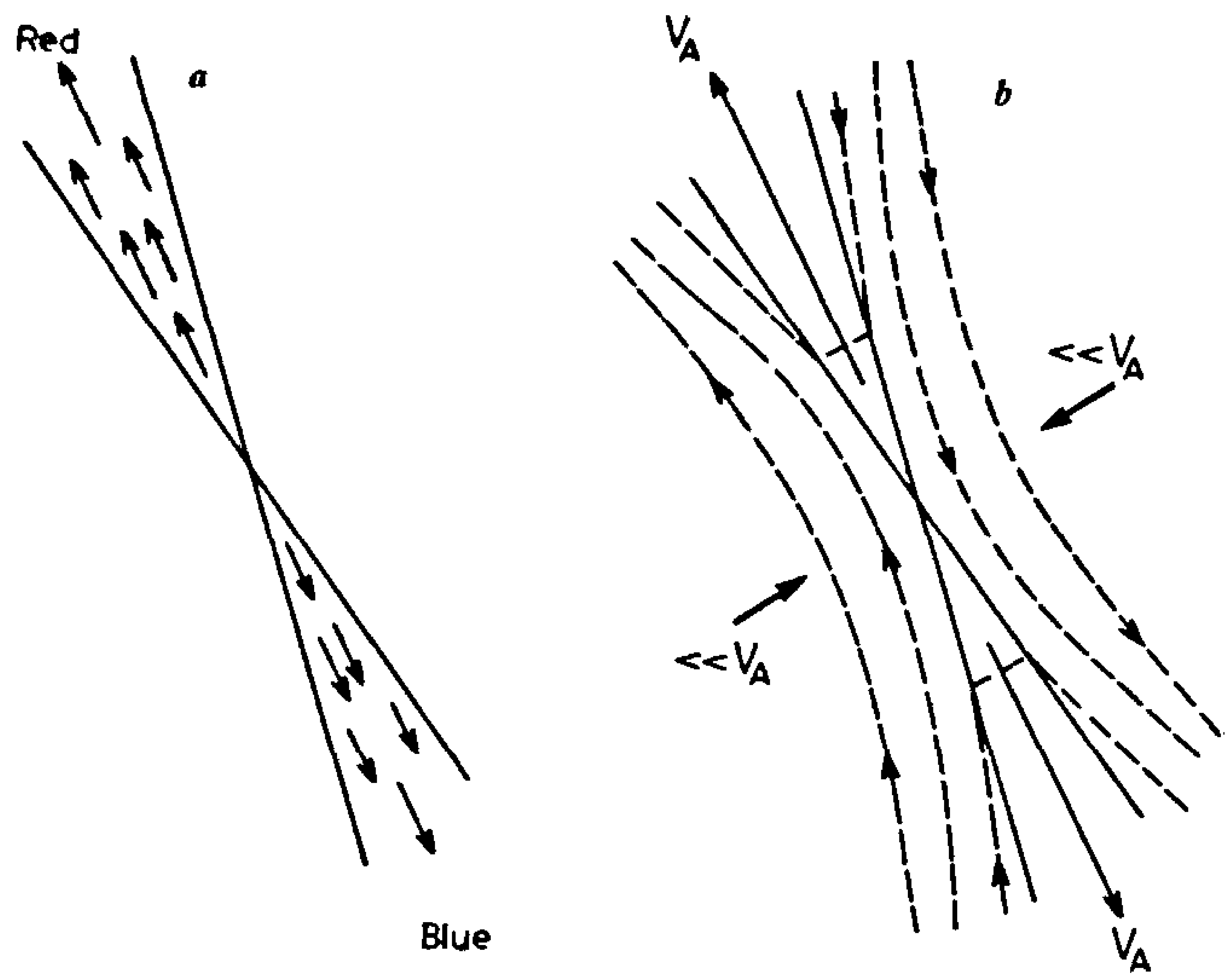

Figure 3. A schematic sketch of a bi-directional jet. ***a***, The expected Doppler shifts change as the spectrometer scan across the jet structure. ***b***, The magnetic field lines (dashed) and the plasma flow (solid arrows) for a reconnection model. The jet speed is of the order of the Alfvén speed, V_A, upstream of the current sheet. The inflow speed is much less than V_A.

association between some small-scale dynamic events and magnetic dipoles.

Explosive events were first seen in the ultraviolet spectra obtained with the Naval Research Laboratory HRTS flown on several rocket flights and spacelab 2 (ref. 1). They were found to be short-lived (60 s), small-scale (1500 km), high velocity (± 150 km/s) flows that occur very frequently over the entire surface on the Sun[2]. Dere *et al.*[3] noted that explosive events are associated with freshly emerged magnetic field and their Doppler velocities are roughly equal to the Alfvén speed in the chromosphere. They concluded that the events result from magnetic reconnection. They also speculated on the possible bi-directional nature of the flows. However, the structure of the flows could not be resolved due to limited time and space coverage.

The ultraviolet spectrometer SUMER (Solar Ultraviolet Measurements of Emitted Radiation) on the spacecraft SOHO (Solar and Heliospheric Observatory) has recently made it possible to observe chromospheric network continuously over an extended period and to discern the spatial structure of the flows associated with these explosive events. Interpreting the evolution of the Si IV 1393 Å line profiles, Innes *et al.*[4] have now shown that explosive events have the bi-directional jets ejected from small sites above the solar surface. The structure of these plasma jets evolves in the manner predicted by theoretical models of magnetic reconnection[5]. This lends support to the view that magnetic reconnection is the fundamental process for accelerating plasma on the Sun.

In order to study density structure as well as element abundance anomaly such as the occurrence of the First Ionization Potential (FIP) effect in the solar atmosphere, an observing sequence based on the research findings on Ne VI/Mg VI by Dwivedi and Mohan[6] was successfully carried out from the SUMER instrument on 20 June 1996. Apart from its main scientific goal as presented[7], jet-like signatures in low-temperature ultraviolet lines have been found[8,9]. High-velocity flows can be clearly seen in the N III 992 Å ($T = 80{,}000$ K) images at the three consecutive slit positions at 72.1, 74.8 and 77.5 Mm above the limb. The direction of shifts changes from blue at 72.1 Mm to red at 77.5 Mm as Figure 1 illustrates. The phenomenon is similar to explosive events observed on the disc. The observations further support the models assuming plasma jets being the source of dynamic event. In this scenario, it is assumed that anti-parallel magnetic fields reconnect at the event site ejecting a bi-directional plasma jet as shown in Figure 2. The change from blue to redshifted emission can well be interpreted also as plasmoids that flow out from the Sun, stop and then fall back; or as series of plasmoids that form in the corona and then flow along oppositely directed paths.

Such observations seem to establish the association between bi-directional jets and magnetic reconnection. There exist a vast collection of data obtained from the SUMER instrument on the spacecraft SOHO and similar bi-directional jets are expected to be seen in the solar atmosphere wherever reconnection takes place. The present and future observations of this kind are likely to provide new clues to a better understanding of how the Sun's magnetic energy feeds its million-degree hot corona and the solar wind.

1. Brueckner, G. E. and Bartoe, J. D. F., *Astrophys. J.*, 1983, **272**, 329–348.
2. Dere, K. P., *Adv. Space Res.*, 1994, **14**, 13–22.
3. Dere, K. P. *et al.*, *J. Geophys. Res.*, 1991, **96**, 9399–9407.
4. Innes, D. E., Inhester, B., Axford, W. I. and Wilhelm, K., *Nature*, 1997, **386**, 811–813.
5. Petschek, H. E., in AAS-NASA Symposium on Solar Flares (ed. Hess, W. N.), NASA-SP 50, 1964, pp. 425–437.
6. Dwivedi, B. N. and Mohan, A., *Solar Phys.*, 1995, **157**, 135–140.
7. Dwivedi, B. N., Curdt, W. and Wilhelm, K., IAU-JD19, Kyoto, 1997, August 26–27.
8. Curdt, W., Dwivedi, B. N. and Innes, D. E., Fifth SOHO Workshop, ESA SP-404, 1997, pp. 303–306.
9. Innes, D. E., Curdt, W., Dwivedi, B. N. and Wilhelm, K., *Solar Phys.*, 1997, submitted.

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