

observations Solar activity studies through coronal X−**ray**

Louise Harra

MATHEMATICAL

THE ROYAL
SOCIETY

PHILOSOPHICAL
TRANSACTIONS ŏ

**MATHEMATICAL,
PHYSICAL**
& ENGINEERING
SCENGIRE

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS ŏ doi: 10.1098/rsta.2000.0550 Phil. Trans. R. Soc. Lond. A 2000 **358**, 641-655

Email alerting service

the article or click **[here](http://rsta.royalsocietypublishing.org/cgi/alerts/ctalert?alertType=citedby&addAlert=cited_by&saveAlert=no&cited_by_criteria_resid=roypta;358/1767/641&return_type=article&return_url=http://rsta.royalsocietypublishing.org/content/358/1767/641.full.pdf)** article - sign up in the box at the top right-hand corner of Receive free email alerts when new articles cite this

<http://rsta.royalsocietypublishing.org/subscriptions> To subscribe to Phil. Trans. R. Soc. Lond. A go to:

THE

PHILOSOPHICAL
TRANSACTIONS

ATHEMATICAL

OYA

Ξ

PHILOSOPHICAL
TRANSACTIONS

Solar activity studies through olar activity studies through
coronal X-ray observations **I X-ray observat**
By Louise Harra

BY LOUISE HARRA
Mullard Space Science Laboratory, University College London,
Holmbury St Mary Dorking, Surrey RH5 6NT, UK Holmbury St Mary, Dorking, Surrey RH5 6NT, UK

Holmbury St Mary, Dorking, Surrey RH5 6NT, UK
The solar corona consists of high-temperature plasma that is contained by a wide The solar corona consists of high-temperature plasma that is contained by a wide
range of magnetic field structures. The cyclic behaviour of solar activity results in
continuing evolution of these structures. This evolutio The solar corona consists of high-temperature plasma that is contained by a wide
range of magnetic field structures. The cyclic behaviour of solar activity results in
continuing evolution of these structures. This evolutio range of magnetic field structures. The cyclic behaviour of solar activity results in continuing evolution of these structures. This evolution can be well studied by observing the X-ray and extreme ultraviolet (EUV) emissi continuing evolution of these structures. This evolution can be well studied by observing the X-ray and extreme ultraviolet (EUV) emission from the hot plasma which delineates the magnetic field in the corona. In this revi ing the X-ray and extreme ultraviolet (EUV) emission from the hot plasma which
delineates the magnetic field in the corona. In this review, the X-ray images obtained
from the Yohkoh mission over more than half a solar cycl delineates the magnetic field in the corona. In this review, the X-ray images obtained
from the Yohkoh mission over more than half a solar cycle and the information they
provide about coronal evolution will be discussed. A from the Yohkoh mission over more than half a solar cycle and the information they
provide about coronal evolution will be discussed. A variety of short-term transient
brightenings observed by Yohkoh, and at EUV wavelength provide about coronal evolution will be discussed. A variety of short-term transient
brightenings observed by Yohkoh, and at EUV wavelengths by the SOHO mission,
will be described and their relevance for coronal heating ev brightenings observed by Yohkoh, and at EUV wavelengths by the SOHO mission,
will be described and their relevance for coronal heating evaluated. Yohkoh observa-
tions have advanced our understanding of solar flares. These will be described and their relevance for coronal heating evaluated. Yohkoh observations have advanced our understanding of solar flares. These important results will be summarized and discussed. Finally, the current view be summarized and discussed. Finally, the current view of the nature of coronal mass ejections as deduced by Yohkoh and SOHO is presented.

Keywords: solar physics; X-ray; solar activity; Yohkoh; SOHO; EUV

1. Introduction

1. Introduction
A clarification of what is happening in the spectacularly dynamic and complex solar
atmosphere has widespread implications for understanding stellar coronae, galaxies **IYSICAL
ENGINEERING** A clarification of what is happening in the spectacularly dynamic and complex solar
atmosphere has widespread implications for understanding stellar coronae, galaxies
and the intracluster medium all of which have million-d A clarification of what is happening in the spectacularly dynamic and conductanosphere has widespread implications for understanding stellar coror and the intracluster medium, all of which have million-degree plasma.
Sinc atmosphere has widespread implications for understanding stellar coronae, galaxies
and the intracluster medium, all of which have million-degree plasma.
Since the launch of the Yohkoh spacecraft (Ogawara *et al.* 1991) in

and the intracluster medium, all of which have million-degree plasma.
Since the launch of the Yohkoh spacecraft (Ogawara *et al.* 1991) in 1991, many
of the previously accepted pictures of the Sun have been overturned. Th Since the launch of the Yohkoh spacecraft (Ogawara *et al.* 1991) in 1991, many
of the previously accepted pictures of the Sun have been overturned. The Yohkoh
spacecraft has provided, for the first time, high-cadence sof of the previously accepted pictures of the Sun have been overturned. The Yohkoh
spacecraft has provided, for the first time, high-cadence soft X-ray imaging, enabling
a deeper understanding of many time-varying phenomena. spacecraft has provided, for the first time, high-cadence soft X-ray imaging, enabling
a deeper understanding of many time-varying phenomena. Our understanding of If and coronal heating, have been advanced dramatically in the past decade.
In the most commonly accepted method of converting magnetic energy into kinetic some of the long-standing problems in solar physics, such as solar flare energetics

and thermal energies is that of magnetic reconnection (see, for example, Priest & The most commonly accepted method of converting magnetic energy into kinetic
and thermal energies is that of magnetic reconnection (see, for example, Priest $\&$
Forbes 1999). This occurs not only in solar plasmas but als and thermal energies is that of magnetic reconnection (see, for example, Priest $\&$ Forbes 1999). This occurs not only in solar plasmas but also in astrophysical and magnetospheric plasmas. Many recent observations of th Forbes 1999). This occurs not only in solar plasmas but also in astrophysical and
magnetospheric plasmas. Many recent observations of the solar corona provide sup-
port for magnetic reconnection as a heating source both on magnetospheric plasmas. Many recent observations of the solar corona provide support for magnetic reconnection as a heating source both on large and small scales.
There exists a wide range of dynamic phenomena ranging from port for magnetic reconnection as a heating source both on large and small scales.
There exists a wide range of dynamic phenomena ranging from network flares (the smallest measurable events) to X-ray bright points, solar f There exists a wide range of dynamic phenomena ranging from network flares (the smallest measurable events) to X-ray bright points, solar flares, and the largest being coronal mass ejections. Figure 1 shows a Yohkoh soft X smallest measurable events) to X-ray bright points, solar flares, and the largest being. coronal mass ejections. Figure 1 shows a Yohkoh soft X-ray image depicting the wide
range of activity which occurs on the Sun at any one time. The bright regions dis-
tributed predominantly in a band 30° above and be range of activity which occurs on the Sun at any one time. The bright regions distributed predominantly in a band 30° above and below the equator are called active regions. These are the hottest regions on the Sun an regions. These are the hottest regions on the Sun and the locations of the largest
Phil. Trans. R. Soc. Lond. A (2000) 358, 641-655 (2000 The Royal Society

HYSICAL
ENGINEERING **ATHEMATICAL**

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS p

**MATHEMATICAL,
PHYSICAL**
& ENGINEERING

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS

Figure 1. A Yohkoh soft X-ray image showing the wide range of structures that exist on the Sun at any one time.

solar and solar and solar and shows a clear example of a coronal
energy releases—solar flares. The north pole shows a clear example of a coronal
hole In this region the field lines are open and hence in the absence of cont energy releases—solar flares. The north pole shows a clear example of a coronal
hole. In this region the field lines are open and hence, in the absence of contained
plasma, there is little soft X-ray emission. Smaller brig energy releases—solar flares. The north pole shows a clear example of a coronal
hole. In this region the field lines are open and hence, in the absence of contained
plasma, there is little soft X-ray emission. Smaller brig hole. In this region the field lines are open and hence, in the absence of contained
plasma, there is little soft X-ray emission. Smaller bright regions are seen all over
the disc, which are known to be X-ray bright points plasma, there is little soft X-ray emission. Smaller bright regions are seen all over
the disc, which are known to be X-ray bright points. On an even smaller scale than
bright points, network brightenings exist. These are the disc, which are known to be X-ray bright points. On an even smaller scale than
bright points, network brightenings exist. These are difficult to see clearly in figure 1
but will be discussed later. There is also a more bright points, network brightenings exist. These are difficult to see clearly in figure 1
but will be discussed later. There is also a more diffuse component in between the
active regions, which is quasi-static. The dynami but will be discussed later. There is also a more diffuse component in between the active regions, which is quasi-static. The dynamics and heating of this wide variety of structures have to be explained. The Yohkoh spacecr active regions, which is quasi-static. The dynamics and heating of this wide variety of structures have to be explained. The Yohkoh spacecraft has been providing unprecedented observations of the X-ray corona. This extensi structures have to be explained. The Yohkoh spacecraft has been providing unprece-
dented observations of the X-ray corona. This extensive dataset was enhanced in
1995, when the ESA/NASA SOHO mission was successfully launc dented observations of the X-ray corona. This extensive dataset was enhanced in 1995, when the ESA/NASA SOHO mission was successfully launched. SOHO has 12 instruments—results from three will be described in this review: 1995, when the ESA/NASA SOHO mission was successfully launched. SOHO has 12
instruments—results from three will be described in this review: the EUV Imaging
Telescope (EIT) (Delaboudiniere *et al.* 1995), the Large Angle S instruments—results from three will be described in this review: the EUV Imaging
Telescope (EIT) (Delaboudiniere *et al.* 1995), the Large Angle Spectroscopic Coron-
agraph (LASCO) (Brueckner *et al.* 1995) and the Coronal (CDS) (Harrison *et al*. 1995).

2. Active regions

2. Active regions
One of the possible sources for heating the active region corona is the occurrence of
numerous microscopic energy releases (microflares or nanoflares). This suggestion was One of the possible sources for heating the active region corona is the occurrence of
numerous microscopic energy releases (microflares or nanoflares). This suggestion was
put forward by Parker (1988). Hard X-ray microflar One of the possible sources for heating the active region corona is the occurrence of
numerous microscopic energy releases (microflares or nanoflares). This suggestion was
put forward by Parker (1988). Hard X-ray microfla numerous microscopic energy releases (microflares or nanoflares). This suggestion was
put forward by Parker (1988). Hard X-ray microflares, with an energy in the range
 5×10^{28} – 10^{30} ergs, were first measured using put forward by Parker (1988). Hard X-ray microflares, with an energy in the range 5×10^{28} -10³⁰ ergs, were first measured using a balloon-borne hard X-ray detector (Lin *et al.* 1984). The soft X-ray equivalent of h 5×10^{28} –10³⁰ ergs, were first measured using a balloon-borne hard X-ray detector (Lin *et al.* 1984). The soft X-ray equivalent of hard X-ray microflares displays itself as intense transient brightenings. The soft as intense transient brightenings. The soft X-ray telescope on board Yohkoh has provided us with the ability to measure energies as low as 10^{27} ergs.

Phil. Trans. R. Soc. Lond. A (2000)

50lar activity studies 643
The energy-frequency distribution of flaring behaviour can be used as a diagnostic for determining whether the transient events observed can supply sufficient energy The energy-frequency distribution of flaring behaviour can be used as a diagnostic
for determining whether the transient events observed can supply sufficient energy
to heat the active region corona. This has been done in for determining whether the transient events observed can supply sufficient energy
to heat the active region corona. This has been done in the case of standard flares
with energies of ca . 10^{32} ergs, and it has been f with energies of ca. 10^{32} ergs, and it has been found that the power law has an index

of less than 2, which means that standard large flares do not supply enough energy
to heat the corona. An investigation into the energy supplied by soft X-ray transient
brightenings has been carried out by Shimizu (1995). to heat the corona. An investigation into the energy supplied by soft X-ray transient were measured from one active region. The energy distribution was determined to brightenings has been carried out by Shimizu (1995). A total of 291 brightenings
were measured from one active region. The energy distribution was determined to
be approximately the same as that for major flares (power-law were measured from one active region. The energy distribution was determined to
be approximately the same as that for major flares (power-law index of 1.5–1.6). A
significant increase in the slope of the energy distributio be approximately the same as that for major flares (power-law index of 1.5–1.6). A
significant increase in the slope of the energy distribution was not found for the lower-
energy brightenings observed by the Soft X-ray Te significant increase in the slope of the energy distribution was not found for the lower-
energy brightenings observed by the Soft X-ray Telescope (SXT). The total estimated
energy input for flare and the smaller transient energy brightenings observed by the Soft X-ray Telescope (SXT). The total estimated
energy input for flare and the smaller transient brightenings was determined to be a
factor of five lower than that required for heating a energy input for flare and the smaller transient brightenings was determined to be a factor of five lower than that required for heating active regions. Events with energies smaller than those observed with SXT and with a factor of five lower than that required for heating active regions
smaller than those observed with SXT and with a higher occ
to be found in order to explain the heating of the corona.
Another new discovery in terms of act Smaller than those observed with SXT and with a higher occurrence rate would need
to be found in order to explain the heating of the corona.
Another new discovery in terms of active regions is that in general they are not

rigidly restrained by the strong magnetic fields. The active regions have been found Another new discovery in terms of active regions is that in general they are not
rigidly restrained by the strong magnetic fields. The active regions have been found
to have sometimes continual expansions with speeds of u rigidly restrained by the strong magnetic fields. The active regions have been found
to have sometimes continual expansions with speeds of up to a few tens of km s⁻¹
(Uchida *et al.* 1992). The expansions occur even outs to have sometimes continual expansions with speeds of up to a few tens of $km s^{-1}$ (Uchida *et al.* 1992). The expansions occur even outside major flaring activity. It is hypothesized that the transient brightenings descri (Uchida *et al.* 1992). The expansions occur even outside major flaring activity. It is hypothesized that the transient brightenings described in the previous paragraph are directly related to the phenomena of expanding a is hypothesized that the transient brightenings described in the previous paragraph

are directly related to the phenomena of expanding active region loops.
Observations of transequatorial coronal loops which join two separate active regions have also been observed (Tsuneta 1996). It has been suggested tha Observations of transequatorial coronal loops which join two separate active regions have also been observed (Tsuneta 1996). It has been suggested that magnetic reconnection is triggered by the active region expansion, wh gions have also been observed (Tsuneta 1996). It has been suggested that magnetic
reconnection is triggered by the active region expansion, which was observed by
Uchida *et al.* (1992). The large loops which are formed aft reconnection is triggered by the active region expansion, which was observed by Uchida *et al.* (1992). The large loops which are formed after the reconnection can heat large areas of plasma in between the active regions. Uchida *et al.* (1992). The large loops which are formed after the reconnection can heat large areas of plasma in between the active regions. It is suggested that the coronal regions outside active regions (the quiet coro heat large areas of plasma in between the active regions. It is suggested that the coronal regions outside active regions (the quiet corona) can be heated continuously as the result of reconnection between active region ma ronal regions outside active regions (the quiet corona) can be heated continuously
the result of reconnection between active region magnetic fields.
The Yohkoh data provide information on coronal temperatures. Since the la

**MATHEMATICAL,
PHYSICAL
& ENGINEERING
SCIENCES** SOHO in 1995, it has been possible to combine the X-ray information with UV data SOHO in 1995, it has been possible to combine the X-ray information with UV data to obtain spectral and imaging information not only for hot The Yohkoh data provide information on coronal temperatures. Since the launch of SOHO in 1995, it has been possible to combine the X-ray information with UV data to obtain spectral and imaging information not only for hot SOHO in 1995, it has been possible to combine the X-ray information with UV data
to obtain spectral and imaging information not only for hot coronal temperatures
(greater than 10^6 K), but also for lower-temperature emi to obtain spectral and imaging information not only for hot coronal temperatures
(greater than 10^6 K), but also for lower-temperature emission $(10^4-10^6$ K). Until
now the view of an active region magnetic loop struc (greater than 10^6 K), but also for lower-temperature emission $(10^4-10^6$ K). Until
now the view of an active region magnetic loop structure has been the following: the
footpoints are anchored in the photosphere (the now the view of an active region magnetic loop structure has been the following: the footpoints are anchored in the photosphere (the surface of the Sun); the loop legs rise up through the subsequent layers of the solar atm If up through the subsequent layers of the solar atmosphere (chromosphere, transition region) with the loop top ending up in the corona (at heights less than 50 000 km above the surface). The transition region has been traditionally considered as a (2 MK). The transition region has been traditionally considered as a thin layer separating the cooler surface (6000 K) from the high-temperature corona (2 MK). However, it has recently been found that transition-region emi thin layer separating the cooler surface (6000 K) from the high-temperature corona thin layer separating the cooler surface (6000 K) from the high-temperature corona (2 MK) . However, it has recently been found that transition-region emission does not in fact exist as a thin layer but mainly as dy (2 MK). However, it has recently been found that transition-region emission does not
in fact exist as a thin layer but mainly as dynamic loop structures which extend high
into the atmosphere—well into the traditional coro in fact exist as a thin layer but mainly as dynamic loop structures which extend high
into the atmosphere—well into the traditional corona (Matthews & Harra-Murnion
1997; Fludra *et al.* 1997). These cool loop structures into the atmosphere—well into the
1997; Fludra *et al.* 1997). These coronal structures (see figure 2).
The different temperature loop 1997; Fludra *et al.* 1997). These cool loop structures coexist spatially with the hot coronal structures (see figure 2).
The different temperature loop structures also behave in a very different man-
ner depending on the

coronal structures (see figure 2).
The different temperature loop structures also behave in a very different man-
ner depending on their temperature. Cool (250 000 K) loops are extremely dynamic,
whereas the hot (2 MK) lo The different temperature loop structures also behave in a very different man-
ner depending on their temperature. Cool (250 000 K) loops are extremely dynamic,
whereas the hot (2 MK) loops are quasi-static over time-scal ner depending on their temperature. Cool (250 000 K) loops are extremely dynamic,
whereas the hot (2 MK) loops are quasi-static over time-scales of an hour (see fig-
ure 2). High flow velocities (*ca*. 100 km s⁻¹) have whereas the hot (2 MK) loops are quasi-static over time-scales of an hour (see figure 2). High flow velocities $(ca. 100 \text{ km s}^{-1})$ have been observed in the cool loops (Brekke *et al.* 1997), whereas flows of only $ca. 2 \text{ km$ (Brekke *et al.* 1997), whereas flows of only $ca. 2 \text{ km s}^{-1}$ have been observed in hot *Phil. Trans. R. Soc. Lond.* A (2000)

DYXO

H

PHILOSOPHICAL
TRANSACTIONS

NEERING

**MATHEMATICAL,
PHYSICAL
& ENGINEERING
SCIENCES ATHEMATICAL**

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS

NGINEERING ATHEMATICAL
IYSICAL

HL

PHILOSOPHICAL
TRANSACTIONS

Figure 2. (a) Images of an active region on the west limb taken simultaneously in a coronal line Fe XVI (2 MK) and transition region line O V (250 000 K). (b) The same active region an hour later. The dramatic changes in Figure 2. (a) Images of an active region on the west limb taken simultaneously in a coronal line
Fe XVI (2 MK) and transition region line O V (250 000 K). (b) The same active region an hour
later. The dramatic changes in later. The dramatic changes in structure in the transition region line are obvious. There is no evidence for the transition region behaving as a transitional layer between the cool surface and the hot corona. evidence for the transition region behaving as a transitional layer between the cool surface and

the hot corona.

loops. It is possible that the cool loops represent a stage in the heating of the hot

loops (Harra-Murnion *et al.* 1999) loops. It is possible that the cool loops.
loops (Harra-Murnion *et al.* 1999).

3. Flares

3. Flares
Our understanding of the flare process has improved dramatically with the data
from the Yohkoh spacecraft. The hot, dense, thermal emission as measured in soft From the Yohkoh spacecraft. The hot, dense, thermal emission as measured in soft
X-rays by the SXT shows the response of the plasma to a flare. The hard X-rays Our understanding of the flare process has improved dramatically with the data
from the Yohkoh spacecraft. The hot, dense, thermal emission as measured in soft
X-rays by the SXT shows the response of the plasma to a flare. from the Yohkoh spacecraft. The hot, dense, thermal emission as measured in soft X-rays by the SXT shows the response of the plasma to a flare. The hard X-rays are produced by electron-ion Bremsstrahlung from highly energe X-rays by the SXT shows the response of the plasma to a flare. The hard X-rays
are produced by electron-ion Bremsstrahlung from highly energetic electrons during
the impulsive phase of flares. The existence of hard X-ray are produced by electron-ion Bremsstrahlung from highly energetic electrons during
the impulsive phase of flares. The existence of hard X-ray sources (greater than
or equal to 30 keV) at the footpoints of the soft X-ray l the impulsive phase of flares. The existence of hard X-ray sources (greater than
or equal to 30 keV) at the footpoints of the soft X-ray loop has been confirmed
from Yohkoh observations by Sakao *et al.* (1994). No signifi or equal to 30 keV) at the footpoints of the soft X-ray loop has been confirmed
from Yohkoh observations by Sakao *et al.* (1994). No significant time lag was found
in the intensity variation of the footpoint kernels, from Yohkoh observations by Sakao *et al.* (1994). No significant time lag was found
in the intensity variation of the footpoint kernels, and hence it is reasonable to
assume that the energetic electrons are moving down b in the intensity variation of the footpoint kernels, and hence it is reasonable to assume that the energetic electrons are moving down both loop legs simultaneously.
This observation represents a common characteristic of t assume that the energetic electrons are moving down both loop legs simultaneously.
This observation represents a common characteristic of the impulsive phase, and is
due to the accelerated electrons streaming down through This observation represents a common characteristic of the impulsive phase, and is due to the accelerated electrons streaming down through the loop legs, from the reconnection point, to the footpoints.
In addition to the h due to the accelerated electrons streaming down through the loop legs, from the

reconnection point, to the footpoints.
In addition to the hard X-ray footpoint sources, a high-energy source can also exist
well above the loop top during the impulsive phase (Masuda *et al.* 1995). The three
hard X-ray so In addition to the hard X-ray footpoint sources, a high-energy source can also exist
well above the loop top during the impulsive phase (Masuda *et al.* 1995). The three
hard X-ray sources can be seen in figure 3. The loo hard X-ray sources can be seen in figure 3. The loop-top source is weaker than the *Phil. Trans. R. Soc. Lond.* A (2000)

Solaractivitystudies ⁶⁴⁵ Downloaded from rsta.royalsocietypublishing.org

HYSICAL
{ ENGINEERING
{ ENGINEERING **ATHEMATICAL**

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS

Ξ

PHILOSOPHICAL
TRANSACTIONS

Figure 3. Hard X-ray image $(33–53 \text{ keV})$ in contours overlaid on a soft X-ray image of the flaring loop. The flare occurred at the west limb on the 13 January 1992. The hard X-ray footpoint Figure 3. Hard X-ray image (33–53 keV) in contours overlaid on a soft X-ray image of the flaring
loop. The flare occurred at the west limb on the 13 January 1992. The hard X-ray footpoint
and loop-top sources can be clear Figure 3. Hard X-ray image (33–53 keV) in contours overlaid on a loop. The flare occurred at the west limb on the 13 January 19, and loop-top sources can be clearly seen (Masuda *et al.* 1995).

and loop-top sources can be clearly seen (Masuda *et al.* 1995).
footpoint sources by a factor of approximately five. The discovery of a loop-top source
has implications for the understanding of the flare energy release m footpoint sources by a factor of approximately five. The discovery of a loop-top source
has implications for the understanding of the flare energy release mechanism. There
are two possible explanations for this loop-top so footpoint sources by a factor of approximately five. The discovery of a loop-top source
has implications for the understanding of the flare energy release mechanism. There
are two possible explanations for this loop-top so has implications for the understanding of the flare energy release mechanism. There are two possible explanations for this loop-top source. The first is that the source represents the reconnection site itself. Secondly, it are two possible explanations for this loop-top source. The first is that the source
represents the reconnection site itself. Secondly, it could be that the reconnection
point is far above the source, and that outflow ejec represents the reconnection site itself. Secondly, it could be that the reconnection
point is far above the source, and that outflow ejected from the reconnection point
is colliding with the higher-density magnetic loops a point is far above the source, and that outflow ejected from the reconnection point
is colliding with the higher-density magnetic loops and forming a shock. A cartoon
of the reconnection configuration derived from the obse

colliding with the higher-density magnetic loops and forming a shock. A cartoon
the reconnection configuration derived from the observations is shown in figure 4.
Another characteristic of the compact flares described abov % of the reconnection configuration derived from the observations is shown in figure 4.
Another characteristic of the compact flares described above is the frequent observation of a hot plasma ejection (plasmoid). These p Another characteristic of the compact flares described above is the frequent observation of a hot plasma ejection (plasmoid). These plasmoids were observed to be very faint and have velocities of the order of hundreds of k vation of a hot plasma ejection (plasmoid). These plasmoids were observed to be very faint and have velocities of the order of hundreds of $km s^{-1}$ (Shibata *et al.* 1995). Magnetic reconnection theory predicts (see, for e faint and have velocities of the order of hundreds of $km s^{-1}$ (Shibata *et al.* 1995).
Magnetic reconnection theory predicts (see, for example, Priest 1982) two oppositely
directed high-speed jets at the Alfvén speed (*ca* Magnetic reconnection theory predicts (see, for
directed high-speed jets at the Alfvén speed (cation of the moving plasmoids are much lower.
Hard X-ray loop-top sources have also been rected high-speed jets at the Alfvén speed $(ca.3000 \text{ km s}^{-1})$. The observed veloci-
s of the moving plasmoids are much lower.
Hard X-ray loop-top sources have also been observed in the decay phase of long
ration events (LD

ties of the moving plasmoids are much lower.
Hard X-ray loop-top sources have also been observed in the decay phase of long
duration events (LDEs). These flares tend to be associated with systems of loops
called post-flare Hard X-ray loop-top sources have also been observed in the decay phase of long duration events (LDEs). These flares tend to be associated with systems of loops called post-flare loops, and can last up to 12 h. It has been duration events (LDEs). These flares tend to be associated with systems of loops
called post-flare loops, and can last up to 12 h. It has been well observed that these
post-flare loops expand and can last for many hours. T called post-flare loops, and can last up to 12 h. It has been well observed that these
post-flare loops expand and can last for many hours. The process of expansion is
believed to be due to ongoing magnetic reconnection. believed to be due to ongoing magnetic reconnection. The newly formed hot loops cool down to appear eventually as $H\alpha$ loops. Schmieder *et al.* (1995) and van Drielbelieved to be due to ongoing magnetic reconnection. The newly formed hot loops cool down to appear eventually as $H\alpha$ loops. Schmieder *et al.* (1995) and van Driel-Gesztelyi *et al.* (1997) found that the cool $H\alpha$ lo cool down to appear eventually as $H\alpha$ loops. Schmieder *et al.* (1995) and van Driel-
Gesztelyi *et al.* (1997) found that the cool $H\alpha$ loops lie tangentially below the hot
loops and rise with a velocity of *ca.* 1 km Gesztelyi *et al.* (1997) found that the cool $H\alpha$ loops lie tangentially below the hot loops and rise with a velocity of *ca*. 1 km s⁻¹ upwards. The hard X-ray sources were found to lie above and slightly overlapping U loops and rise with a velocity of ca . 1 km s⁻¹ upwards. The hard X-ray sources were

O found to lie above and slightly overlapping the soft X-ray loop. As time progresses
 \bullet the hard X-ray source and the soft X-ra \bigcirc found to lie above and slightly overlapping the soft X-ray loop. As time progresses the hard X-ray source and the soft X-ray loop become further apart, with both the hard X-ray source and the soft X-ray loop rising hard X-ray source and the soft X-ray loop rising with time (Harra-Murnion *et al.*) 98). This suggests that the mechanism which allows the flare to persist for so many
urs is ongoing reconnection.
Observations of an LDE have also shown that the rise speed of the inner loop
d the speed of the footpoint se

hours is ongoing reconnection.
Observations of an LDE have also shown that the rise speed
and the speed of the footpoint separation is ca . 10 km s⁻¹ (^T
The movement of the loop and footpoints is thought to be d peed of the inner loop (Tsuneta *et al.* 1992).
due to the rise of the Observations of an LDE have also shown that the rise speed of the inner loop and the speed of the footpoint separation is $ca.10 \text{ km s}^{-1}$ (Tsuneta *et al.* 1992). The movement of the loop and footpoints is thought to be d The movement of the loop and footpoints is thought to be due to the rise of the *Phil. Trans. R. Soc. Lond.* A (2000)

FIXR footpoint sources evaporation
Figure 4. A cartoon of the reconnection configuration derived from the observations for a
compact flare (Masuda *et al.* 1995) reconnection configuration derived from the compact flare (Masuda *et al.* 1995).

compact flare (Masuda *et al.* 1995).
reconnection point (X-point location). The loop-top region has a sharp cusp-like reconnection point (X-point location). The loop-top region has a sharp cusp-like
structure suggestive of the reconnection site being located at the top of the flare loop.
The outer loops tend to have a larger temperature t **MATHEMATICAL,
PHYSICAL
& ENGINEERING
SCIENCES** reconnection point (X-point location). The loop-top region has a sharp cusp-like
structure suggestive of the reconnection site being located at the top of the flare loop.
The outer loops tend to have a larger temperature t structure suggestive of the reconnection site being located at the top of the flare loop.
The outer loops tend to have a larger temperature than the inner loops following the
rise phase of the flare. This is consistent wit The outer loops tend to have a larger temperature than the inner loops following the rise phase of the flare. This is consistent with the idea that the recently reconnected outer loops are not whereas the inner loops are n outer loops are hot whereas the inner loops are now cooling and are no longer being ter loops are hot whereas the inner loops are now cooling and are no longer being
ated (Tsuneta 1996).
The imaging techniques described here have been enhanced by the availability
high-sensitivity spectroscopic information

heated (Tsuneta 1996).
The imaging techniques described here have been enhanced by the availability
of high-sensitivity spectroscopic information. The emission lines are broadened in
excess of their thermal width and occas The imaging techniques described here have been enhanced by the availability
of high-sensitivity spectroscopic information. The emission lines are broadened in
excess of their thermal width and occasionally exhibit excess So f high-sensitivity spectroscopic information. The emission lines are broadened in excess of their thermal width and occasionally exhibit excess emission on the blue \blacktriangleright side of the rest wavelength during the rise p excess of their thermal width and occasionally exhibit excess emission on the blue
side of the rest wavelength during the rise phase of flares. A study of 190 solar flares
observed by Yohkoh was carried out by Mariska (199 side of the rest wavelength during the rise phase of flares. A study of 190 solar flares
observed by Yohkoh was carried out by Mariska (1994). He found that 25% of flares
show spatial shifts of the emitting plasma, and the observed by Yohkoh was carried out by Mariska (1994). He found that 25% of flares
show spatial shifts of the emitting plasma, and there is a trend in the average value of
the velocity with distance from the Sun centre whic show spatial shifts of the emitting plasma, and there is a trend in the average value of
the velocity with distance from the Sun centre which suggests radial mass motions.
This is explained by the release of energy heating the velocity with distance from the Su
This is explained by the release of en
pressures which induce plasma flow.
The excess line-broadening above the This is explained by the release of energy heating the plasma, and the change in
pressures which induce plasma flow.
The excess line-broadening above the thermal width is also observed and is ascribed

pressures which induce plasma flow.
The excess line-broadening above the thermal width is also observed and is ascribed
to non-thermal velocity. The physical process which produces this effect is not well
understood. Befor The excess line-broadening above the thermal width is also observed and is ascribed
to non-thermal velocity. The physical process which produces this effect is not well
understood. Before the results from Yohkoh, it was su to non-thermal velocity. The physical process which produces this effect is not well
understood. Before the results from Yohkoh, it was surmised that the large non-
thermal velocities observed during the rise phase of flar understood. Before the results from Yohkoh, it was surmised that the large non-
thermal velocities observed during the rise phase of flares were due to the evapo-
ration of hot plasma early in the flare. Alexander *et al.* thermal velocities observed during the rise phase of flares were due to the evaporation of hot plasma early in the flare. Alexander *et al.* (1998) have examined the relationship between the time of the maximum in the non relationship between the time of the maximum in the non-thermal velocity and the *Phil. Trans. R. Soc. Lond.* A (2000)

EFRING ATHEMATICAL

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS

ATHEMATICAL

DYX

H

PHILOSOPHICAL
TRANSACTIONS

 $Solar\ activity\ studies$
time of the first significant hard X-ray burst (which determines the flare start). They
found that the non-thermal velocity was at its peak or else declining from the peak time of the first significant hard X-ray burst (which determines the flare start). They
found that the non-thermal velocity was at its peak or else declining from the peak
at the time of the first hard X-ray burst. This su time of the first significant hard X-ray burst (which determines the flare start). They
found that the non-thermal velocity was at its peak or else declining from the peak
at the time of the first hard X-ray burst. This su found that the non-thermal velocity was at its peak or else declining from the peak
at the time of the first hard X-ray burst. This suggests that the non-thermal veloc-
ity measurements may not be due to evaporation of the at the time of the first hard X-ray burs
ity measurements may not be due to ϵ
information on the flare initialization.
Although there is plenty of evidence ity measurements may not be due to evaporation of the plasma, but can provide
information on the flare initialization.
Although there is plenty of evidence to support magnetic reconnection providing

Although there is plenty of evidence to support magnetic reconnection providing
energy input in many different aspects of coronal activity, there are also some who
argue against it (Hudson & Khan 1997). For example, as men energy input in many different aspects of coronal activity, there are also some who energy input in many different aspects of coronal activity, there are also some who argue against it (Hudson & Khan 1997). For example, as mentioned earlier, the reconnection jets that have been described are not as fast argue against it (Hudson & Khan 1997). For example, as mentioned earlier, the reconnection jets that have been described are not as fast as the jets which are predicted by simple Petschek theory, which suggest they move a reconnection jets that have been described are not as fast as the jets which are
predicted by simple Petschek theory, which suggest they move at approximately
the Alfvén speed. However, more sophisticated theory (Priest & predicted by simple Petschek theory, which suggest they move at approximately
the Alfvén speed. However, more sophisticated theory (Priest & Forbes 1999) gives
outflow and inflow speeds much slower than the Alfvén speed. R the Alfvén speed. However, more sophisticated theory (Priest & Forbes 1999) gives
outflow and inflow speeds much slower than the Alfvén speed. Reconnection theory
also requires inflow towards the reconnection site. Variou outflow and inflow speeds much slower than the Alfvén speed. Reconnection theory
also requires inflow towards the reconnection site. Various forms of outflow have been
observed and inflow has never been observed. Hudson & also requires inflow towards the reconnection site. Various forms of outflow have been
observed and inflow has never been observed. Hudson $\&$ Khan (1997) also mention
the frequent occurrences of homologous flares, which observed and inflow has never been observed. Hudson $\&$ Khan (1997) also mention
the frequent occurrences of homologous flares, which occur in the same location and
have many similarities, although this may be explained have many similarities, although this may be explained in a reconnection model that the field returns it to the original configuration. $\overline{\delta}$

4. Coronal mass ejections

4. Coronal mass ejections
Many of the transient events described in the previous sections may add to the solar
wind content. For example, the expanding active regions and jets mentioned above Many of the transient events described in the previous sections may add to the solar
wind content. For example, the expanding active regions and jets mentioned above
will all add to the mass loss of the corona. Most of our Many of the transient events described in the previous sections may add to the solar
wind content. For example, the expanding active regions and jets mentioned above
will all add to the mass loss of the corona. Most of our wind content. For example, the expanding active regions and jets mentioned above
will all add to the mass loss of the corona. Most of our knowledge about coronal mass
ejections (CMEs) is derived from white light coronagrap will all add to the mass loss of the corona. Most of our knowledge about coronal mass
ejections (CMEs) is derived from white light coronagraph data. Pre-Yohkoh it proved
difficult to assign any strong connection between th ejections (CMEs) is derived from white light coronagraph data. Pre-Yohkoh it proved
difficult to assign any strong connection between the soft X-ray corona and the white-
light CMEs. Yohkoh SXT, with its high-time cadence difficult to assign any strong connection between the soft X-ray corona and the white-
light CMEs. Yohkoh SXT, with its high-time cadence and sensitivity, has provided
the opportunity to study some of the X-ray phenomena r light CMEs. Yohkoh SXT, with its high-time cadence and sensitivity, has provided
the opportunity to study some of the X-ray phenomena related to CMEs in much
more detail. The coronagraph LASCO onboard SOHO is now providing **HYSICAL**
ENGINEERING
CIENCES the opportunity to study some of the X-ray phenomena related to CMEs in much
more detail. The coronagraph LASCO onboard SOHO is now providing continuous
observations of white-light data providing the ability to observe the more detail. The coronagraph LASCO onboa
observations of white-light data providing th
that may be related to soft X-ray features.
The first Yohkoh event, which was direct observations of white-light data providing the ability to observe the outward flows
that may be related to soft X-ray features.
The first Yohkoh event, which was directly related to white-light observations

of a lament eruption and a CME, was a streamer reformation (Hiei *et al*. 1993). The first Yohkoh event, which was directly related to white-light observations of a filament eruption and a CME, was a streamer reformation (Hiei *et al.* 1993). The prominence eruption and coronal mass ejection occurred of a filament eruption and a CME, was a streamer reformation (Hiei *et al.* 1993).
The prominence eruption and coronal mass ejection occurred before the streamer
appeared. Subsequently, the X-ray coronal helmet streamer s The prominence eruption and coronal mass ejection occurred before the streamer appeared. Subsequently, the X-ray coronal helmet streamer slowly expanded. This event also showed strong evidence of coronal depletion (Hudson appeared. Subsequently, the X-ray coronal helmet streamer slowly expanded. This
event also showed strong evidence of coronal depletion (Hudson 1996), which permit-
ted a determination of the CME launch time. The coronal 'd event also showed strong evidence of coronal depletion
ted a determination of the CME launch time. The
provide one of the best X-ray signatures of CMEs.
There are a number of examples in which dimm \blacktriangleright ted a determination of the CME launch time. The coronal 'dimming' observations \blacktriangleright provide one of the best X-ray signatures of CMEs.
There are a number of examples in which dimming appears above LDEs. This

tends to be the most obvious type of dimming (Hudson *et al*. 1996), although an There are a number of examples in which dimming appears above LDEs. This tends to be the most obvious type of dimming (Hudson *et al.* 1996), although an observational constraint is that they must be observed at the limb. tends to be the most obvious type of diversational constraint is that they must associated with CMEs for many years.
The first example of dimming associated servational constraint is that they must be observed at the limb. LDEs have been
sociated with CMEs for many years.
The first example of dimming associated with a halo CME was found by Sterling
Hudson (1997) Halo CMEs whic

associated with CMEs for many years.
The first example of dimming associated with a halo CME was found by Sterling & Hudson (1997). Halo CMEs which are directed along the Sun-Earth axis are characterized by a diffuse cloud The first example of dimming associated with a halo CME was found by Sterling & Hudson (1997). Halo CMEs which are directed along the Sun-Earth axis are characterized by a diffuse cloud of material lying symmetrically aro & Hudson (1997). Halo CMEs which are directed along the Sun–Earth axis are characterized by a diffuse cloud of material lying symmetrically around the solar occulting disc. There was a flare observed in X-rays at 14:00 on characterized by a diffuse cloud of material lying symmetrically around the solar occulting disc. There was a flare observed in X-rays at 14:00 on the 7 April 1997.
From the dimming measurements an estimate of the mass lo occulting disc. There was a flare observed in X-rays at 14:00 on the 7 Apr
From the dimming measurements an estimate of the mass loss could be n
was found that the dimming occurred over a projected area of 10^{20} cm⁻² was found that the dimming occurred over a projected area of 10^{20} cm⁻² suggesting

Downloaded from rsta.royalsocietypublishing.

E. Harra

L. Harra Downloaded from rsta.royalsocietypublishing.org

Figure 5. A full Sun soft X-ray image showing the source of a CME. The panel on the left shows
the preflare S-type structure, and the panel on the right shows the cusp-shaped structure which Figure 5. A full Sun soft X-ray image showing the source of a CME. The panel on the left shows
the preflare S-type structure, and the panel on the right shows the cusp-shaped structure which
developed following the CME (c the preflare S-type structure, and the panel on the right shows the cusp-shaped structure which developed following the CME (courtesy A. C. Sterling).

developed following the CME (courtesy A. C. Sterling).

that a mass of $ca. 10^{14}$ g was ejected. It is surmised that at least part of the CME

mass is detected via the X-ray dimming measurements. Most of the ejected mass that a mass of $ca.10^{14}$ g was ejected. It is surmised that at least part of the CME mass is detected via the X-ray dimming measurements. Most of the ejected mass comes from two regions which lie close to the ends of the that a mass of $ca.10^{14}$ g was ejected. It is surmised that at least part of the CME mass is detected via the X-ray dimming measurements. Most of the ejected mass comes from two regions which lie close to the ends of the mass is detected via the X-ray dimming measurements. Most of the ejected mass comes from two regions which lie close to the ends of the preflare S structure. This S structure changes morphology dramatically into a cusp-sha the section comes from two regions which lie close to the ends of the preflare S structure. This S structure changes morphology dramatically into a cusp-shaped structure following the flare (see figure 5). The levels of di S structure changes morphology dramatically into a cusp-shaped structure following
the flare (see figure 5). The levels of dimming remain high for roughly three days.
It is suggested that the two areas of dimming represent the flare (see figure 5). The levels of dimming remain high for roughly three days.
It is suggested that the two areas of dimming represent a magnetic flux rope which
erupts. The cusp shape which develops is thought to be It is suggested that the two areas of dimming represent a magnetic flux rope which erupts. The cusp shape which develops is thought to be due to the reconnection of the magnetic field lines following the eruption.
Followin upts. The cusp shape which develops is thought to be due to the reconnection of
e magnetic field lines following the eruption.
Following this work which showed the sigmoidal (S-shaped or inverse S-shape)
probably related t

morphology related to a CME, a statistical study has been carried out by Canfield Following this work which showed the sigmoidal (S-shaped or inverse S-shape) morphology related to a CME, a statistical study has been carried out by Canfield *et al.* (1999). It was found that, from a study of 117 active morphology related to a CME, a statistical study has been carried out by Canfield *et al.* (1999). It was found that, from a study of 117 active regions, those which have sigmoidal structures are 68% more likely to be have sigmoidal structures are 68% more likely to be eruptive than those with non-
sigmoidal structures. The other factor which increases the likelihood of eruption is have sigmoidal structures are 68% more likely to be eruptive than those with non-
sigmoidal structures. The other factor which increases the likelihood of eruption is
the size of the sunspot area. Other factors such as sigmoidal structures. The other factor which increases
the size of the sunspot area. Other factors such as the
will improve the prediction of eruptions in the future. will improve the prediction of eruptions in the future.
5. Bright points

It has been well established that there is an association of coronal X-ray bright points with bipolar magnetic features. The relationship between the magnetic field
and the overlying atmosphere has been examined in detail by the Michelson Doppler It has been well established that there is an association of coronal X-ray bright
points with bipolar magnetic features. The relationship between the magnetic field
and the overlying atmosphere has been examined in detail points with bipolar magnetic features. The relationship between the magnetic field
and the overlying atmosphere has been examined in detail by the Michelson Doppler
Interferometer (MDI) onboard SOHO, and EIT. The magnetic and the overlying atmosphere has been examined in detail by the Michelson Doppler
Interferometer (MDI) onboard SOHO, and EIT. The magnetic field outside of active
regions is continuously replenishing. From the MDI movies t regions is continuously replenishing. From the MDI movies the flux concentrations *Phil. Trans. R. Soc. Lond.* A (2000)

**MATHEMATICAL,
PHYSICAL
& ENGINEERING
SCIENCES**

ROYAL

THE

PHILOSOPHICAL
TRANSACTIONS \overline{c}

 X (arcsec)
Figure 6. Two magnetograms of a quiet Sun region taken a day apart. The white areas show
positive polarity and the black areas show negative polarity. The contours show coronal emission Figure 6. Two magnetograms of a quiet Sun region taken a day apart. The white areas show
positive polarity and the black areas show negative polarity. The contours show coronal emission
in Fe XII from EIT (Pres & Phillips positive polarity and the black areas show negative polarity. The contours show coronal emission
in Fe XII from EIT (Pres & Phillips 1999). A-F mark the regions of coronal emission.

frequently break into small fragments and collide with other flux fragments. Pres $\&$ Frequently break into small fragments and collide with other flux fragments. Pres $\&$ Phillips (1999) have followed the time evolution of magnetic flux from birth to decay and found that it is very well correlated with t frequently break into small fragments and collide with other flux fragments. Pres &
Phillips (1999) have followed the time evolution of magnetic flux from birth to decay
and found that it is very well correlated with the c Phillips (1999) have followed the time evolution of magnetic flux from birth to decay
and found that it is very well correlated with the coronal emission. Figure 6 shows two
magnetograms showing the bipolar field with coro and found that it is very well correlated with the coronal emission. Figure 6 shows two magnetograms showing the bipolar field with coronal emission above it. Calculations of the total radiative and conductive flux are com magnetograms showing the bipolar field with coronal emission above it. Calculations
of the total radiative and conductive flux are comparable to the magnetic energy
available from the associated magnetic field.
Non-thermal of the total radiative and conductive flux are comparable to the magnetic energy

bright points have a tendency to show brightness variations. Kundu *et al*. (1994) investigated whether these variations have any similarity to the standard flares which bright points have a tendency to show brightness variations. Kundu *et al.* (1994) investigated whether these variations have any similarity to the standard flares which take place in active regions. One of the most impor investigated whether these variations have any similarity to the standard flares which
take place in active regions. One of the most important aspects of this question is
whether there is any evidence of non-thermal proces take place in active regions. One of the most important aspects of this question is
whether there is any evidence of non-thermal emission. Even in the cases of long-
lasting LDEs there is always some evidence of non-therma whether there is any evidence of non-thermal emission. Even in the cases of long-
lasting LDEs there is always some evidence of non-thermal processes. A joint cam-
paign was carried out with the Nancay radioheliograph and lasting LDEs there is always some evidence of non-thermal processes. A joint campaign was carried out with the Nancay radioheliograph and Yohkoh SXT in 1992.
The Nancay data are obtained at five frequencies ranging between paign was carried out with the Nancay radioheliograph and Yohkoh SXT in 1992.
The Nancay data are obtained at five frequencies ranging between 150 and 450 MHz.
It was confirmed that the X-ray bright point flares give rise The Nancay data are obtained at five frequencies ranging between 150 and 450 MHz.
It was confirmed that the X-ray bright point flares give rise to non-thermal radio
emission in addition to the soft X-ray emission. The dura It was confirmed that the X-ray bright point flares give rise to non-thermal radio
emission in addition to the soft X-ray emission. The duration of the radio emission
is shorter than the soft X-ray emission. The existence emission in addition to the soft X-ray emission. The duration of the radio emission
is shorter than the soft X-ray emission. The existence and behaviour of the relation-
ship between the non-thermal radio emission and the is shorter than the soft X-ray emission. The existence and behaviour of the relation-
ship between the non-thermal radio emission and the thermal soft X-ray emission
has many similarities and strengthens the relationship b ship between the non-thermal radio emission and the thermal soft X-ray emission
has many similarities and strengthens the relationship between flaring bright points
and standard flares. This suggests that the processes inv cases. d standard flares. This suggests that the processes involved are similar in both
ses.
Yohkoh has provided the perfect opportunity to determine whether there is a cycle
pendence of the number of X-ray bright points. There h

cases.
Yohkoh has provided the perfect opportunity to determine whether there is a cycle
dependence of the number of X-ray bright points. There has been some dispute about
whether the number of bright points would increase Yohkoh has provided the perfect opportunity to determine whether there is a cycle
dependence of the number of X-ray bright points. There has been some dispute about
whether the number of bright points would increase, decr dependence of the number of X-ray bright points. There has been some dispute about
whether the number of bright points would increase, decrease or stay the same during
the cycle. Nakakubo & Hara (2000) investigated the num whether the number of bright points would increase, decrease or stay the same during
the cycle. Nakakubo & Hara (2000) investigated the number of bright points seen
with the SXT using an automated technique during the per the cycle. Nakakubo & Hara (2000) investigated the number of bright points seen
with the SXT using an automated technique during the period from December 1992
(close to solar maximum) to August 1997 (close to solar mini with the SXT using an automated technique during the period from December 1992
(close to solar maximum) to August 1997 (close to solar minimum). The number of
X-ray bright points did not change significantly until approxim (close to solar maximum) to August 1997 (close to solar minimum). The number of X-ray bright points did not change significantly until approximately 1995. As sunspot minimum approached, the number of bright points reached X-ray bright points did not change significantly until approximately 1995. As sunspot
minimum approached, the number of bright points reached a maximum when the
sunspot number was at its lowest. However, an investigation i minimum approached, the number of bright points reached a maximum when the sunspot number was at its lowest. However, an investigation into the effects of the background intensity showed that the observed increase in the n background intensity showed that the observed increase in the number of bright *Phil. Trans. R. Soc. Lond.* A (2000)

NEERING ATHEMATICAL ಕ

NEERING **MATHEMATICAL**

Downloaded from rsta.royalsocietypublishing.

650 $L.$ Harra Downloaded from rsta.royalsocietypublishing.org

NGINEERING MATHEMATICAL **YSICAL**

ROYA

FELL

PHILOSOPHICAL
TRANSACTIONS

Figure 7. Temporal variation of network flares observed in soft X-ray and radio emission. The
image at the top shows the soft X-ray image with network brightenings marked by white hoxes Figure 7. Temporal variation of network flares observed in soft X-ray and radio emission. The image at the top shows the soft X-ray image with network brightenings marked by white boxes.
The four figures below show example Figure 7. Temporal variation of network flares observed in soft X-ray and radio emission. The image at the top shows the soft X-ray image with network brightenings marked by white boxes. The four figures below show example

1997).
points was due to the drop in background intensity. When this effect is allowed for,
it appears that there is no correlation between the number of bright points and the it appears that there is no correlation between the number of bright points and the points was di
it appears th
solar cycle.

6. Network brightenings

6. Network brightenings
As mentioned previously there has been an investigation into whether active regions
are heated by numerous flarings on small scales. The number of brightenings in As mentioned previously there has been an investigation into whether active regions
are heated by numerous flarings on small scales. The number of brightenings in
an active region in the energy range $10^{27}-10^{29}$ ergs i As mentioned previously there has been an investigation into whether active regions
are heated by numerous flarings on small scales. The number of brightenings in
an active region in the energy range $10^{27}-10^{29}$ ergs i are heated by numerous flarings on small scales. The number of brightenings in
an active region in the energy range $10^{27}-10^{29}$ ergs is too small to provide all the
heating for the active region. The heating of the qui an active region in the energy range $10^{27}-10^{29}$ ergs is too small to provide all the
heating for the active region. The heating of the quiet corona has also been inves-
tigated. For a direct link between soft X-ray br heating for the active region. The heating of the quiet corona has also been inves-
tigated. For a direct link between soft X-ray brightenings and the Parker model of
nanoflares/microflares, there should be evidence of th tigated. For a direct link between soft X-ray brightenings and the Parker model of nanoflares/microflares, there should be evidence of the release of non-thermal electrons, which are also observed during standard solar fla nanoflares/microflares, there should be evidence of the release of non-thermal election.

Phil. Trans. R. Soc. Lond. A (2000)

-
Mainerring
Enginerring **ATHEMATICAL**

THE ROYAI

PHILOSOPHICAL
TRANSACTIONS p ATHEMATICAL

ROYAL

THE

PHILOSOPHICAL
TRANSACTIONS

**ATHEMATICAL,
IYSICAL
ENGINEERING
''ENCES**

UNXO

THE

PHILOSOPHICAL
TRANSACTIONS

Solar activity studies 651
The soft X-ray enhancements found are smaller than recorded X-ray bright points The soft X-ray enhancements found are smaller than recorded X-ray bright points
by at least an order of magnitude. For all of the SXR events measured there was
a radio event which correlated in space and time (see figure 7 **NEERING**
ES The soft X-ray enhancements found are smaller than recorded X-ray bright points
by at least an order of magnitude. For all of the SXR events measured there was
a radio event which correlated in space and time (see figure 7 by at least an order of magnitude. For all of the SXR events measured there was
a radio event which correlated in space and time (see figure 7). The observations
are very similar to solar flare observations but on a much s a radio event which correlated in space and time (see figure 7). The observations
are very similar to solar flare observations but on a much smaller scale, and have
hence been given the name network flares or network brigh

are very similar to solar flare observations but on a much smaller scale, and have
hence been given the name network flares or network brightenings. The extrapolated
frequency is one brightening every three seconds on the hence been given the name network flares or network brightenings. The extrapolated frequency is one brightening every three seconds on the total solar surface, with each event having an energy between 10^{25} and 10^{27} frequency is one brightening every three seconds on the total solar surface, with each event having an energy between 10^{25} and 10^{27} ergs. There are some differences between the network flares and standard flares. each event having an energy between
between the network flares and standa
lower and the durations are shorter.
The variable nature of brightenings a tween the network flares and standard flares. The temperatures observed are much
wer and the durations are shorter.
The variable nature of brightenings at the network junctions has also been observed
the UV by Harrison (19

I lower and the durations are shorter.

The variable nature of brightenings at the network junctions has also been observed

I in the UV by Harrison (1997) using the coronal diagnostic spectrometer (CDS) The variable nature of brightenings at the network junctions has also been observed
in the UV by Harrison (1997) using the coronal diagnostic spectrometer (CDS)
onboard SOHO. There appear to be more brightenings in the coo in the UV by Harrison (1997) using the coronal diagnostic spectrometer (CDS)
onboard SOHO. There appear to be more brightenings in the cooler transition region
emission than in the coronal emission. The energy distributio onboard SOHO. There appear to be more brightenings in the cooler transition region
emission than in the coronal emission. The energy distribution of the heating in the
quiet Sun has been determined by Krucker & Benz (1998 emission than in the coronal emission. The energy distribution of the heating in the quiet Sun has been determined by Krucker & Benz (1998) using the EIT onboard SOHO. The energy of the events measured in this case ranged quiet Sun has been determined by Krucker & Benz (1998) using the EIT onboard SOHO. The energy of the events measured in this case ranged between 8×10^{24} and 1.6×10^{26} ergs. The brightenings were measured as 3σ SOHO. The energy of the events measured in this case ranged between 8×10^{24} and 1.6×10^{26} ergs. The brightenings were measured as 3σ above the background level. These brightenings were found to have a frequen and 1.6×10^{26} ergs. The brightenings were measured as 3σ above the background
level. These brightenings were found to have a frequency distribution of the form
 $f(E) = F_0 E^{-\delta}$, with δ having a value between 2.3 level. These brightenings were found to have a frequency distribution of the form $f(E) = F_0 E^{-\delta}$, with δ having a value between 2.3 and 2.6. Since the power law is greater than 2, there is a strong possibility that the $f(E) = F_0 E^{-\delta}$, with δ having a value between 2.3 and 2.6. Since the power law is greater than 2, there is a strong possibility that the microflaring is the dominant heating mechanism for the quiet corona. The low-ener p greater than 2, there is a strong possibility that the microflaring is the dominant
heating mechanism for the quiet corona. The low-energy cut-off is due to sensitivity
limitations, and hence there could be many more small heating mechanism for the quiet corona. The low-energy cut-off is due to sensitivity
limitations, and hence there could be many more smaller energy events. Indeed Par-
nell (this issue) describes recent work with TRACE dat limitations, and hence there could be many more smaller energy nell (this issue) describes recent work with TRACE data going an lower in size of event and obtains a similar value of power law.
Gallagher *et al.* (1999) hav Il (this issue) describes recent work with TRACE data going an order of magnitude
wer in size of event and obtains a similar value of power law.
Gallagher *et al.* (1999) have analysed rapid-time cadence data of quiet Sun

lower in size of event and obtains a similar value of power law.
Gallagher *et al.* (1999) have analysed rapid-time cadence data of quiet Sun EUV emission observed by the CDS. The transient brightenings are observed both Gallagher *et al.* (1999) have analysed rapid-time cadence data of quiet Sun EUV emission observed by the CDS. The transient brightenings are observed both in the transition region line (O V) and in the chromospheric line emission observed by the CDS. The transient brightenings are observed both in the transition region line (O V) and in the chromospheric line (He I) suggesting a coupling between the chromosphere and the transition region. transition region line (O V) and in the chromospheric line (He I) suggesting a coupling
between the chromosphere and the transition region. There is a clear association of
brightenings in the network with downflows of the between the chromosphere and the transition region. There is a clear association of brightenings in the network with downflows of the order of 20 km s⁻¹. The properties of the network regions are different to the cell r brightenings in the network with downflows of the order of 20 $km s^{-1}$. The properties. heating mechanisms for the cell and network regions.
 7. Diffuse corona

The diffuse component of the corona has very different characteristics from the more The diffuse component of the corona has very different characteristics from the more
dynamic features that have been described above. Priest *et al.* (1998) have inves-
tigated the heating mechanism of this component. The The diffuse component of the corona has very different characteristics from the more
dynamic features that have been described above. Priest *et al.* (1998) have inves-
tigated the heating mechanism of this component. The dynamic features that have been described above. Priest *et al.* (1998) have inves-
tigated the heating mechanism of this component. The diffuse emission consists of
large-scale diffuse loops. The temperature profile alon tigated the heating mechanism of this component. The diffuse emission consists of large-scale diffuse loops. The temperature profile along such a loop is measured and this is compared with various models. There are several large-scale diffuse loops. The temperature profile along such a loop is measured and
this is compared with various models. There are several possible heating mechanisms.
Firstly, Alfvén waves may dissipate either by phase this is compared with various models. There are several possible heating mechanisms.
Firstly, Alfvén waves may dissipate either by phase mixing releasing energy or resonant absorption. Another option, as mentioned earlier, Firstly, Alfvén waves may dissipate either by phase mixing releasing energy or resonant absorption. Another option, as mentioned earlier, is reconnection in many small current sheets scattered throughout the structure that nant absorption. Another option, as mentioned earlier, is reconnection in many small
current sheets scattered throughout the structure that form in response to twisting
or braiding of the magnetic field lines. This may in current sheets scattered throughout the structure that form in response to twisting
or braiding of the magnetic field lines. This may in turn lead to an MHD turbulent
state. From this particular example it is found that th or braiding of the magnetic field lines. This may in turn lead to an MHD turbulent state. From this particular example it is found that the heating is uniform throughout the diffuse loops, and is not focused at the footpoints or loop-top (see figure 8).
 $8.$ The future

All the structures that have been described in this paper are magnetic in origin. To increase our understanding further we need to address the relationship between

PHYSICAL
& ENGINEERING
SCIENCES MATHEMATICAL

THE ROYAL

PHILOSOPHICAL
TRANSACTIONS $\overline{0}$

**MATHEMATICAL,
PHYSICAL
& ENGINEERING
SCIENCES**

ROYA

THE

PHILOSOPHICAL
TRANSACTIONS

distance (Mm)
Figure 8. Comparison of the temperature profiles for different theoretical mechanisms (solid
curves) with the observed temperature profile determined from SXT of a large coronal loop Figure 8. Comparison of the temperature profiles for different theoretical mechanisms (solid curves) with the observed temperature profile determined from SXT of a large coronal loop (Priest *et al.* 1998) (a) Exponential Figure 8. Comparison of the temperature profiles for different theoretical mechanisms
curves) with the observed temperature profile determined from SXT of a large corona
(Priest *et al.* 1998). (a) Exponential decay over 0

(Priest *et al.* 1998). (*a*) Exponential decay over 0.1*L*; (*b*) localized at top; (*c*) uniform.
the magnetic field and the solar atmosphere. The mission which will follow from
the success of the Yohkoh mission is the the magnetic field and the solar atmosphere. The mission which will follow from
the success of the Yohkoh mission is the Japanese solar-B mission. The launch date
will be in 2004, Solar-B will place the first optical teles the magnetic field and the solar atmosphere. The mission which will follow from
the success of the Yohkoh mission is the Japanese solar-B mission. The launch date
will be in 2004. Solar-B will place the first optical teles the success of the Yohkoh mission is the Japanese solar-B mission. The launch date
will be in 2004. Solar-B will place the first optical telescope in space. The emphasis
of the Yohkoh mission was to focus on energetic phen will be in 2004. Solar-B will place the first optical telescope in space. The emphasis
of the Yohkoh mission was to focus on energetic phenomena. Solar-B will concen-
trate on understanding the connection between the fineof the Yohkoh mission was to focus on energetic phenomena. Solar-B will concentrate on understanding the connection between the fine-scale magnetic field in the photosphere and the structure and dynamics in the entire sola the on understanding the connection between the fine-scale magnetic field in the otosphere and the structure and dynamics in the entire solar atmosphere.
There will be three instruments onboard: a 0.5 m optical telescope w

photosphere and the structure and dynamics in the entire solar atmosphere.
There will be three instruments onboard: a 0.5 m optical telescope with the ability
to measure photospheric magnetic and velocity fields at 0.2 ar There will be three instruments onboard: a 0.5 m optical telescope with t
to measure photospheric magnetic and velocity fields at 0.2 arcsec (150 km)
imaging spectrometer, which will have velocity resolution of *ca*. 10 k h the ability
m); an EUV
, and spatial
to image the to measure photospheric magnetic and velocity fields at 0.2 arcsec (150 km); an EUV imaging spectrometer, which will have velocity resolution of ca . 10 km s⁻¹, and spatial resolution better than 2 arcsec; and an X-ra imaging spectrometer, which will have velocity resolution of ca . 10 km s⁻¹, and spatial resolution better than 2 arcsec; and an X-ray/EUV imaging telescope to image the corona and transition region with better than 2 a

9. Summary

9. Summary
The wide range of solar activity that has been observed by the Yohkoh mission since
its launch in 1991 has been described. The characteristics of the small-scale structures The wide range of solar activity that has been observed by the Yohkoh mission since
its launch in 1991 has been described. The characteristics of the small-scale structures
such as bright points and network brightenings h The wide range of solar activity that has been observed by the Yohkoh mission since
its launch in 1991 has been described. The characteristics of the small-scale structures
such as bright points and network brightenings ha its launch in 1991 has been described. The characteristics of the small-scale structures
such as bright points and network brightenings have shown similarities with larger
flares. A direct relationship has been found betwe such as bright points and network brightenings have shown similarities with larger
flares. A direct relationship has been found between the variation of the magnetic
flux at the surface and the coronal plasma above a brigh flares. A direct relationship has been found between the variation of the magnetic
flux at the surface and the coronal plasma above a bright point. The number of
bright points has been found not to vary with solar cycle. A flux at the surface and the coronal plasma above a bright point. The number of bright points has been found not to vary with solar cycle. Analysis of the larger active regions has shown that only some of the heating is pro bright points has been found not to vary with solar cycle. Analysis of the larger active
regions has shown that only some of the heating is provided by transient brightenings.
Transequatorial loops connecting active region *Phil. Trans. R. Soc. Lond.* A (2000)

Solar activity studies 653
Sun. The active-region loop structures expand with velocities of the order of tens Sun. The active-region loop structures expand with velocities of the order of tens
of $km s^{-1}$. The standard solar flares have shown many clues towards understanding
the energetics and initialization. The main candidate is Sun. The active-region loop structures expand with velocities of the order of tens
of $km s^{-1}$. The standard solar flares have shown many clues towards understanding
the energetics and initialization. The main candidate is the energetics and initialization. The main candidate is magnetic reconnection. The first soft X-ray signature for coronal mass ejections has been found. It takes the form the energetics and initialization. The main candidate is magnetic reconnection. The first soft X-ray signature for coronal mass ejections has been found. It takes the form of dimming or depletion of the coronal material, a

structure.

dimming or depletion of the coronal material, and is related to a sigmoidal-type
ructure.
The future of solar physics looks set to enhance these exciting discoveries with the
xt. Japanese solar mission, solar-B. The future of solar physics looks set to enhance these exciting discoveries with the next Japanese solar mission, solar-B.

References

- Alexander, D., Harra-Murnion, L. K., Khan, J. I. & Matthews, S. A. 1998 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29494L.235[aid=539136])* 494, 235–238. Alexander,D., Harra-Murnion, L. K., Khan, J. I. & Matthews, S. A. 1998 *Astrop.*
235–238.
Brekke, P., Kjeldseth-Moe, O. & Harrison, R. A. 1997 *[Solar Phys.](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0038-0938^28^29175L.511[aid=539137])* 175, 511–521.
Bruckhor, G. E. (and 14 others) 1995 *Solar Phys.*
- 235–238.
Brekke, P., Kjeldseth-Moe, O. & Harrison, R. A. 1997 *Solar Phys.*
Brueckner, G. E. (and 14 others) 1995 *Solar Phys.* **162**, 357–402.
Canfold B. C. Hudson, H. S. & McKenzie, D. E. 1999 *Ceenhys.* L
-
- Brekke, P., Kjeldseth-Moe, O. & Harrison, R. A. 1997 *Solar Phys.* 175, 511–521.
Brueckner, G. E. (and 14 others) 1995 *Solar Phys.* 162, 357–402.
Canfield, R. C., Hudson, H. S. & McKenzie, D. E. 1999 *[Geophys. Res. Lett.](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0094-8276^28^2926L.627[aid=539139,doi=10.1016/0273-1177^2895^2900731-S])* Brueckner, G. E. (and 14 others) 1995 *Solar Phys.* 162, 357–402.
Canfield, R. C., Hudson, H. S. & McKenzie, D. E. 1999 *Geophys. Res.*
Delaboudiniere, J.-P. (and 14 others) 1995 *Solar Phys.* 162, 291–312.
Fludra A. Brokk

- Canneid,R. C., Hudson, H. S. & McKenzie, D. E. 1999 Geophys. Res. Lett. 20, 027–050.
Delaboudiniere, J.-P. (and 14 others) 1995 Solar Phys. 162, 291–312.
Fludra, A., Brekke, P., Harrison, R. A., Mason, H. E., Pike, C. D., 1aboudiniere, J.-P. (and 14 others)
1997 *Solar Phys.* 175, 487–509.
1997 *Solar Phys.* 175, 487–509. Fludra,A., Brekke, P., Harrison, R. A., Mason, H. E., Pike, C. D., Thompson, W. & Young, P.
1997 Solar Phys. 175, 487–509.
Gallagher, P. T., Phillips, K. J. H., Harra-Murnion, L. K., Baudin, F. & Keenan, F. P. 1999
4 stro
- *Astron. Astrophys.* **175**, 487–509
 Astron. Astrophys. **348**, 251.
 Astron. Astrophys. **348**, 251.
 Astron. I. K. Schmider Gallagher,P. T., Phillips, K. J. H., Harra-Murnion, L. K., Baudin, F. & Keenan, F. P. 1999
Astron. Astrophys. 348, 251.
Harra-Murnion, L. K., Schmieder, B., van Driel-Gesztelyi, L., [Sato, J., Plunkett, S. P., Rudawy,](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-6361^28^29337L.911[aid=539143,springer=1])
P. B
- P., Rompolt, B., Akioka, M., Sakao, T. & Ichimoto, K. 1998 *Astron. Astrophys.* ³³⁷, 911{920. Harra-Murnion, L. K., Schmieder, B., van Driel-Gesztelyi, L., Sato, J., Plunkett, S. P., Rudawy, P., Rompolt, B., Akioka, M., Sakao, T. & Ichimoto, K. 1998 *[Astron. Astrophys.](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-6361^28^29345L.1011[aid=539144,springer=1])* **337**, 911–920. Harra-Murnion, L. K., Matthew Harra-Murnion, L. K., Matthews, S. A., Hara, H.
1011.
Harrison, R. A. 1997 *Solar Phys.* 175, 467–485.
Harrison, B. A. (and 38 others) 1995. Solar Phys.
-
- 1011.
Harrison,R. A. 1997 *Solar Phys.* **175**, 467–485.
Harrison, R. A. (and 38 others) 1995 *Solar Phys.* **162**, 233–290.
- Hiei,E., Hundhausen, A. J. & Sime, D. G. 1993 *Geophys. Res. Lett.* 20, 2785-2788.
- Hudson,K. A. (and 38 others) 1995 *Solar Phys.* 102, 235–290.
Hiei, E., Hundhausen, A. J. & Sime, D. G. 1993 *Geophys. Res. Lett.* 20, 2785–2788.
Hudson, H. S. 1996 Magnetodynamic phenomena in the solar atmosphere. Protot **MATHEMATICAL,
PHYSICAL
& ENGINEERING**
SCIENCES ei, E., Hundhausen, A. J. & Sime, D. G. 1993 *Geophys. Res. Lett.* **20**, 2785–2788.
Idson, H. S. 1996 Magnetodynamic phenomena in the solar atmosphere. Prototypes of stellar
magnetic activity. In *Proc. 153rd Coll. Int. As May 1995* (ed. Y. Uchida, T. Kosugi & H. S. Hudson, Makuhari, Japanetic activity. In *Proc. 153rd Coll. Int. Astronomical Union, Makuhari, Japanety 1995* (ed. Y. Uchida, T. Kosugi & H. S. Hudson), p. 89. Dordrecht: Kluwer magnetic activity. In Proc. 153rd Coll. Int. Astronomical Union, Makuhari, Japan, 22–27
May 1995 (ed. Y. Uchida, T. Kosugi & H. S. Hudson), p. 89. Dordrecht: Kluwer.
Hudson, H. S. & Khan, J. I. 1997 *Magnetic reconnection*
	- *May 1995* (ed. Y. Uchida, T. Kosugi & H. S. Hudson), p. 89. Dordre
idson, H. S. & Khan, J. I. 1997 *Magnetic reconnection in the solar*
Bentley & J. T. Mariska). ASP Conference Series, vol. 111, p. 135.
idson, H. S. Acto Hudson, H. S. & Khan, J. I. 1997 *Magnetic reconnection in the solar atmospher*
Bentley & J. T. Mariska). ASP Conference Series, vol. 111, p. 135.
Hudson, H. S., Acton, L. W. & Freeland, S. L. 1996 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29470L.629[aid=539148,doi=10.1086/177894])* 470, 629
	- Bentley & J. T. Mariska). ASP Conference Series, vol. 111,
Hudson, H. S., Acton, L. W. & Freeland, S. L. 1996 *Astrophys*
Krucker, S. & Benz, A. O. 1998 *Astrophys. Jl* 501, 213–216.
Krucker, S. Benz, A. O. Bestian, T. S.
	-
	- Hudson,H. S., Acton, L. W. & Freeland, S. L. 1996 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29488L.499[aid=539150,doi=10.1086/304686])* **470**, 629–632.
Krucker, S. & Benz, A. O., Bastian, T. S. & Acton, L. W. 1997 *Astrophys. Jl* **488**, 499–502.
Krucker, S., Benz, A. O., Bastian, T. S. & Ac Krucker, S. & Benz, A. O. 1998 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29431L.155[aid=539151])* 501, 213–216.
Krucker, S., Benz, A. O., Bastian, T. S. & Acton, L. W. 1997 *Astrophys. Jl* 488, 499–50
Kundu, M. R., Shibasaki, K., Enome, S. & Nitta, N. 1994 *Astrophys. Jl*
	- Kundu, M. R., Shibasaki, K., Enome, S. & Nitta, N. 1994 *Astrophys. Jl* 431, 155–158.
⁴ Mariska, J. 1994 *Astrophys. Jl* 434, 756–765.
	-
	- Kundu,M. R., Shibasaki, K., Enome, S. & Nitta, N. 1994 *Astrophys. Jl* 431, 155–158.
Mariska, J. 1994 *Astrophys. Jl* 434, 756–765.
Masuda, S., Kosugi, T., Hara, H., Sakao, T., Shibata, K. & Tsuneta, S. 1995 *Proc. Astr.* arıska, J. 1994 *As*
asuda, S., Kosugi,
Jl 47, 677–689.
atthoug S. & Hor Masuda, S., Kosugi, T., Hara, H., Sakao, T., Shibata, K. & Tsuneta, S.
 Jl 47, 677–689.

	Matthews, S. & Harra-Murnion, L. K. 1997 *Solar Phys.* 175, 541–551.

	Nakakuba, K. & Harra-Hurnion, L. K. 1997 *Solar Phys.* 175, 5
	- *Jl*47, 677–689.
Matthews, S. & Harra-Murnion, L. K. 1997 *Solar Phys.* 175, 541
Nakakubo, K. & Hara, H. 2000 *Adv. Space Res.* (In the press.)
	-
	- C Nakakubo, K. & Hara, H. 2000 *Adv. Space Res.* (In the press.)

	 Lin, R. P., Schwartz, R. A., Kane, S. R., Pelling, R. M. & Hurley, K. C. 1984 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29283L.421[aid=539154,doi=10.1086/162321])* 283,

	△ | 421-425.
		- O[gawara,](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0038-0938^28^29136L.1[aid=539155])[Y., Takano, T.,](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0038-0938^28^29136L.1[aid=539155]) Kato, T., Kosugi, T., Tsuneta, S., Watanabe, T. & Kondo, I. 1991 421–425.
Solar Phys. 136, 1–16.
Solar Phys. 136, 1–16.
rker F. N. 1988. *Astronh* Ogawara, Y., Takano, T., Kato, T., Kosugi, T., *Solar Phys.* **136**, 1–16.
Parker, E. N. 1988 *Astrophys. Jl* **330**, 474–479.
Pros. P. & Phillips. K. J. H. 1999. *Astrophys.* Jl 5
		-
		- *SolarPhys.* **136**, 1–16.
Parker, E. N. 1988 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29510L.73[aid=539157])* **330**, 474–479.
Pres, P. & Phillips, K. J. H. 1999 *Astrophys. Jl* **510**, 73–76.
Priort, E. 1989 *E.C. P. 7*, 363, 445. Pres, P. & Phillips, K. J. H. 1999 *Astrophys. Jl* 510, 73–76.
Priest, E. 1982 *F.C.P.* 7, 363–445.
		-

Phil. Trans. R. Soc. Lond. A (2000)

DYA

 \mathbf{L} H

PHILOSOPHICAL
TRANSACTIONS

ATHEMATICAL

Priest, E. & Forbes, T. 1999 *Magnetic reconnection*. Cambridge University Press.

- **IATHEMATICAL,
HYSICAL
¿ ENGINEERING**
CIENCES Priest, E. & Forbes, T. 1999 *Magnetic reconnection*. Cambridge University Press.
Priest, E. R., Foley, C. R., Heyverts, J., Arbour, T. D., Culhane, J. L. & Acton, L. W. 1998
Nature 393 545–547 **E. & Forbes, T. 19**
iest, E. R., Foley, C. R.
Nature **393**, 545–547.
kao T. Kosugi, T. Ma Priest,E. R., Foley, C. R., Heyverts, J., Arbour, T. D., Culhane, J. L. & Acton, L. W. 1998
 Nature **393**, 545–547.

Sakao, T., Kosugi, T., Masuda, S., Yaji, K., Inda-Koide, M. & Makishima, K. 1994 *[Adv. Space](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0273-1177^28^2917L.67[aid=539159,doi=10.1063/1.871778])*
 Res.
	- *Rature* **393**, 545–
kao, T., Kosugi, ¹
Res. **17**, 67–70.
amiodor B. Hoin Sakao,T., Kosugi, T., Masuda, S., Yaji, K., Inda-Koide, M. & Makishima, K. 1994 *Adv. Spa*
Res. 17, 67–70.
Schmieder, B., Heinzel, P., Wiik, J. E., Lemen, J. R. & Hiei, E. 1995 *Solar Phys.* 156, 337.
Shihata, K. Masuda,
		- Res. 17, 67–70.
Schmieder, B., Heinzel, P., Wiik, J. E., Lemen, J. R. & Hiei, E. 1995 Solar Phys. 156, 337.
Shibata, K., Masuda, S., Shimojo, M., Hara, H., Yokoyama, T., Tsuneta, S., Kosugi, T. &
	- Ogawara, Y. 1995 *Astrophys. Jl* 451, 83-86.
	- Shimizu, T. 1995 *Proc. Astr. Soc. Jl* 47, 251-263.
	- Ogawara, Y. 1995 *[Astrophys. Jl](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0004-637X^28^29491L.55[aid=539162])* 451, 83–86.
Shimizu, T. 1995 *Proc. Astr. Soc. Jl* 47, 251–263.
Sterling, A. C. & Hudson, H. S. 1997 *Astrophys. Jl* 491, 55–59.
Tsuneta S. 1996 *Astrophys. Jl* 456, 63–65. Shimizu, T. 1995 *Proc. Astr. Soc. Jl* 47, 251-
Sterling, A. C. & Hudson, H. S. 1997 *Astroph*
Tsuneta, S. 1996 *Astrophys. Jl* 456, 63–65.
Tsuneta S. Hara H. Shimizu, T. Axton J.
	-
	- Sterling,A. C. & Hudson, H. S. 1997 *Astrophys. Jt* 491, 55–59.
Tsuneta, S. 1996 *Astrophys. Jl* 456, 63–65.
Tsuneta, S., Hara, H., Shimizu, T., Axton, L., Strong, K., Hudson, H. & Ogawara, Y. 1992 *Proc.*
Astr. Soc. Il 4 uneta, S. 1996 *Astrophys.*

	uneta, S., Hara, H., Shimiz
 Astr. Soc. Jl 44, 63–69.

	bida V. McAllister A. S Astr. Soc. Jl 44, 63–69.
Uchida, Y., McAllister, A., Strong, K. T., Ogawara, Y., Shimizu, T., Matsumoto, R. & Hudson,
	- H. S. 1992 *Proc. Astr. Soc. Jl* 44, 155-160. van Driel-Gesztely[i, L., Wiik, J. E., Sch](http://ernesto.ingentaselect.com/nw=1/rpsv/cgi-bin/linker?ext=a&reqidx=/0038-0938^28^29174L.151[aid=539164])mieder, B., Tarbell, T., Kitai, R., Funakoshi, Y. & Anwar B. 1992 *Proc. Astr. Soc. Jl* 44, 155–160.

	van Driel-Gesztelyi, L., Wiik, J. E., Schmieder, B., Tarbell, T., Kitai, R., Fu
		- H. S. 1992 *Proc. Astr. Soc. Jl* 44, 155–1
n Driel-Gesztelyi, L., Wiik, J. E., Schr
Anwar, B. 1997 *Solar Phys.* 174, 151.

Discussion

L. GOLUB (*Harvard Smithsonian Center for Astrophysics, USA*). The word 'diffuse' \mathcal{L} . GOLUB (*Harvard Smithsonian Center for Astrophysics, USA*). The word 'diffuse' occurs several times in this paper. I find it hard to believe that in a hot magnetized plasma, wherein the magnetic field is highly L. GOLUB (*Harvard Smithsonian Center for Astrophysics*, USA). The word 'diffuse' occurs several times in this paper. I find it hard to believe that in a hot magnetized plasma, wherein the magnetic field is highly organize occurs several times in this paper. I find it hard to believe that in a hot magnetized plasma, wherein the magnetic field is highly organized, there would be any diffuse corona. I prefer to use the word 'unresolved'. Could plasma, wherein the magnetic field is highly organized, there would be any diffuse corona. I prefer to use the word 'unresolved'. Could you comment on the expected size scales transverse to magnetic field dissection?

corona. I preier to use the word unresolved. Could you comment on the expected
size scales transverse to magnetic field dissection?
L. HARRA. Yes, I agree. In fact the work that I described assumes that the 'diffuse'
stru size scales transverse to magnetic lield dissection:
L. HARRA. Yes, I agree. In fact the work that I described assumes that the 'diffuse'
structures take the form of loops. In the paper by Priest *et al.* (1998), there is L. HARRA. Yes, I agree. In fact the work that I structures take the form of loops. In the paper image showing the loop structure very clearly.

E. R. PRIEST (*University of St Andrews, UK*). The magnetic field in the corona
of course dominates the plasma structure transverse to the field while its structure
of course dominates the plasma structure transverse to th E. R. PRIEST (*University of St Andrews*, UK). The magnetic field in the corona
of course dominates the plasma structure transverse to the field while its structure
along the field is determined by purely (mechanical and E. R. PRIEST (*University of St Andrews, UK*). The magnetic field in the corona
of course dominates the plasma structure transverse to the field while its structure
along the field is determined by purely (mechanical and of course dominates the plasma structure transverse to the field while its structure
along the field is determined by purely (mechanical and thermal) plasma effects. If
the magnetic field and plasma were static and the pla along the field is determined by purely (mechanical and thermal) plasma effects. If
the magnetic field and plasma were static and the plasma pressure at the coronal base
were uniform, the plasma pressure would be stratifie the magnetic field and plasma were static and the plasma pressure at the coronal base
were uniform, the plasma pressure would be stratified purely vertically and would
show no effect of the magnetic field. The fact that yo were uniform, the plasma pressure would be stratified purely vertically and would
show no effect of the magnetic field. The fact that you see coronal loops implies the
corona is much more complex than that! The expected tr show no effect of the magnetic field. The fact that you see coronal loops implies the corona is much more complex than that! The expected transverse scales that Leon asked about are likely to be produced by two effects: th corona is much more complex than that! The expected transverse scales that Leon
asked about are likely to be produced by two effects: the field-line footpoints moving
around on granular scales would tend to produce coronal asked about are likely to be produced by two effects: the field-line footpoints moving
around on granular scales would tend to produce coronal scales of the same size;
and intrinsic coronal instabilities such as an MHD ra around on granular scales would tend to produce variations *in situ* in the corona. and intrinsic coronal instabilities such as an MHD radiative instability would tend
to produce variations in situ in the corona.
Y. UCHIDA (*University of Tokyo, Japan*). There is a possibility that those mag-

N. UCHIDA (*University of Tokyo*, *Japan*). There is a possibility that those magnetically driven mass losses due to CME and active-region expansion may be more important than the usual Parker wind in magnetically active Y. UCHIDA (*University of Tokyo, Japan*). There is a possibility the usual Parker wind in magnetically active stars.

netically driven mass losses due to UME and active-region expansion may be more
important than the usual Parker wind in magnetically active stars.
E. R. PRIEST. The solar wind itself has several components; a fast solar wi from the open coronal holes and a sporadic slow solar wind coming from the open coronal holes and a sporadic slow solar wind coming from mainly closed
regions. The solar wind has a very complex structure: for example, the E. R. PRIEST. The solar wind itself has several components; a fast solar wind coming
from the open coronal holes and a sporadic slow solar wind coming from mainly closed
regions. The solar wind has a very complex structure from the open coronal holes and a sporadic slow solar wind coming from mainly closed
regions. The solar wind has a very complex structure: for example, the fast wind has
both plume and interplume components and the slow wi regions. The solar wind has a v
both plume and interplume co
one of which you mentioned. *Phil. Trans. R. Soc. Lond.* A (2000)

**IATHEMATICAL,
HYSICAL
< ENGINEERING
CIENCES**

ROYAL

THE

PHILOSOPHICAL
TRANSACTIONS $\overline{0}$ Solar activity studies 655
L. HARRA. Yes, as well as the active-region expansion that I mentioned there are L. HARRA. Yes,
high speed jets.

R. E. Pudritz (*McCaster University, Canada*). Do your observations show any mgn speed jess.
R. E. PUDRITZ (*McCaster University*, C
evidence for coronal heating by waves?

L. HARRA. Most evidence that I have described has favoured heating by reconnection. There have been a few studies which have indicated evidence of wave heating by examining the line broadening (non-thermal velocity) as a function of temperature, and also looking for periodic motions. However, the evidence is not strong. by examining the line broadening (non-thermal velocity) as a function of temperature, and also looking for periodic motions. However, the evidence is not strong. Of course, there is strong evidence for the production of wa ature, and also looking for periodic motions. I
Of course, there is strong evidence for the prodisuch as Moreton waves associated with flares.

Of course, there is strong evidence for the production of waves in other phenomena,
such as Moreton waves associated with flares.
E. R. PRIEST. I think it's fair to say that, before the Yohkoh/SOHO era, theorists
were equa E. R. PRIEST. I think it's fair to say that, before the Yohkoh/SOHO era, theorists
were equally divided: it could be waves or it could be reconnection. Now, in the light
of SOHO observations, there's much more evidence in E. R. PRIEST. I think it's fair to say that, before the Yohkoh/SOHO era, theorists
were equally divided: it could be waves or it could be reconnection. Now, in the light
of SOHO observations, there's much more evidence in O were equally divided: it could be waves or it could be reconnection. Now, in the light of SOHO observations, there's much more evidence in favour of reconnection, but substantial wave heating may still be occurring. I t of SOHO observations, there's much more evidence in favour of reconnection, but
substantial wave heating may still be occurring. I think you have to keep an open
mind and not rule them out. There may well be several mechan substantial wave heating may still be occurring. I think you have to keep an open
mind and not rule them out. There may well be several mechanisms at work heating
the corona, but if there were only one then reconnection is mind and not rule them out. There may well be several mechan
the corona, but if there were only one then reconnection is m
been shown to be the probable cause of X-ray bright points.

Interest corona, but if there were only one then reconnection is most likely since it has
been shown to be the probable cause of X-ray bright points.
D. LYNDEN-BELL (*Queen's University, Belfast, UK*). Certainly, magnetohy D. LYNDEN-BELL (*Queen's University, Belfast, UK*). Certainly, magnetohydrodynamic waves are likely to be travelling upwards in the Sun. The question at issue is whether the heating due to their dissipation is the main so D. LYNDEN-BELL (*Queen's University, Belfast, UK*). Certainly, magnetohydrody-
namic waves are likely to be travelling upwards in the Sun. The question at issue is
whether the heating due to their dissipation is the main s whether the heating due to their dissipation is the main source of coronal heating or microflaring causes the major heating source via superthermal particles generated whether the heating due to their dissipation is the main source of coronal heating or
microflaring causes the major heating source via superthermal particles generated
at reconnections of the magnetic field. While I am a b microflaring causes the major heating source via superthermal par
at reconnections of the magnetic field. While I am a believer in reco
major source, there is no doubt that wave heating does occur too.

at reconnections of the magnetic field. While I am a believer in reconnection as the
major source, there is no doubt that wave heating does occur too.
L. HARRA. I agree that wave heating also must occur. However, most of t the state of the countries in the double tends to must occur. However, most of the observa-
L. HARRA. I agree that wave heating also must occur. However, most of the observa-
tional evidence tends towards small-scale recon L. HARRA. I
tional eviden
of heating.

PHILOSOPHICAL
TRANSACTIONS ŏ

ATHEMATICAL

ROYAL

 $\mathbf{\underline{u}}$

PHILOSOPHICAL
TRANSACTIONS