Two Ribbon Flares: Theory and Observation

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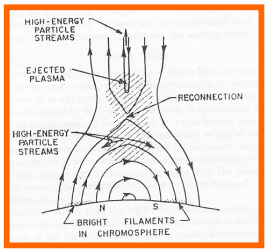

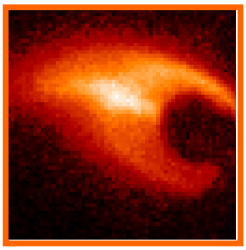

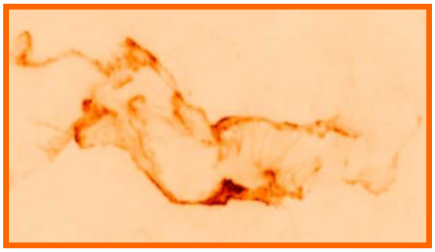

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Outline

- Properties of 2 ribbon flares
- The standard model
- Observational evidence for the standard model
- Driving the flare
- A 2 ribbon flare seen by TRACE
- Ribbons and Field
- 3-D interpretations

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Introduction

Solar Flares are often classified into two types:
compact flares and two ribbon flares.

Hα flare imaging observations show a subset of flares with (spreading) ribbons of emission from the chromosphere.

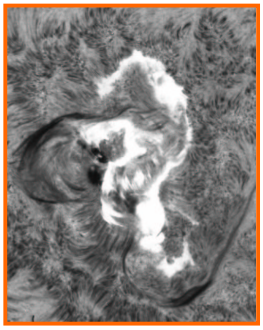

Image: BBSO

Two ribbon flares tend to be
- larger
- more energetic
- more likely to be associated with an eruption

Extended gradual phase indicates energy input into the corona and chromosphere for up to several hours.

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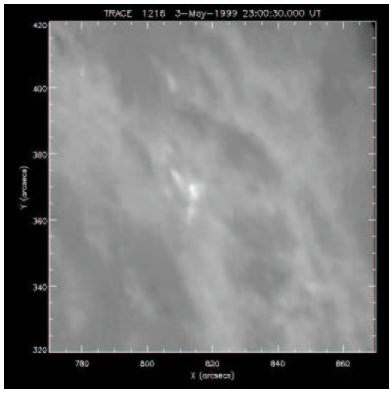
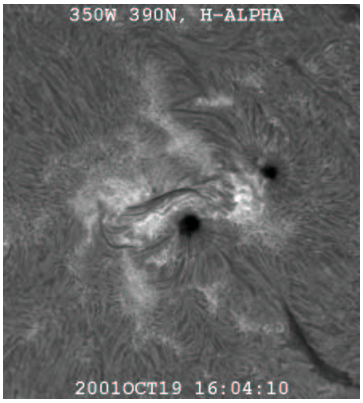
Flare Movies



Compact Flare - TRACE 1216A
movie2



2 ribbon flare BBSO Hα

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Active region and 'quiet sun' 2-ribbon flares

Various classes of 2-Ribbon flares are observed (ordered in size and duration)

•Impulsive 2-ribbon flares in active regions

•Slow long duration events in active regions

•Quiet sun (filament) eruptions - maybe not flares?

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The Standard Two Ribbon Model - ubiquitous features

Coronal Reconnection at current sheet or X-line

- in wake of rising filament or flux rope
- as result of shear applied along an arcade,
- due to reconnection of anti-parallel and initially open magnetic fields

Acceleration of particles associated with this coronal reconnection

flare ribbons generated in various wavelengths at chromosphere
due to collisional excitation or conductive heating

Heated Chromospheric material 'evaporates' upwards

Forms (arcade of) post-flare loops

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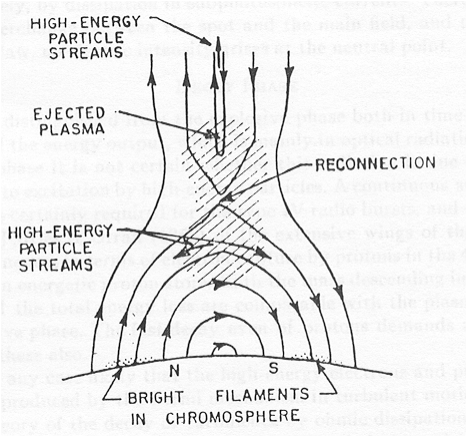
‘Standard’ model - Carmichael-Sturrock-Hirayama-Kopp-Pneuman



Sturrock 1966

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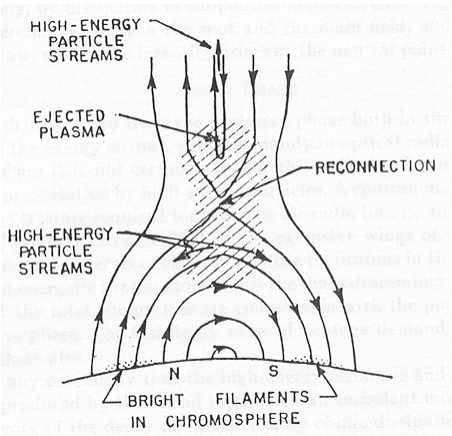
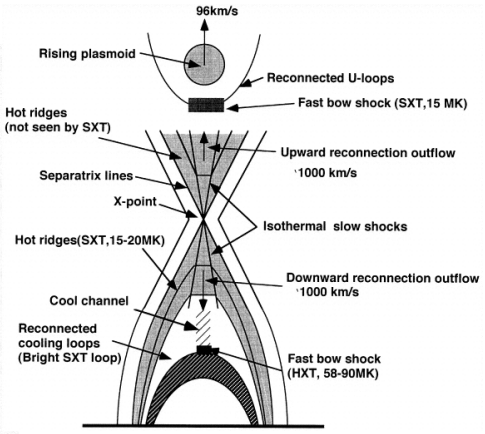
‘Standard’ model

This has evolved to keep pace with observations



Sturrock 1966



Tsuneta 1997

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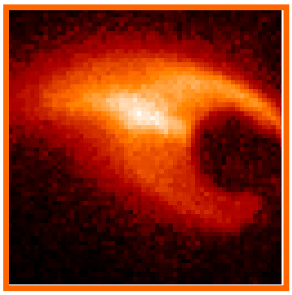
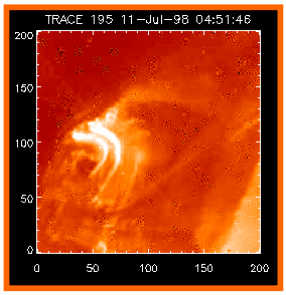
Observational Support for the Standard Model:

(1) Coronal Cusps





Shape lends qualitative support to coronal reconnection temperature structure. Also, late-phase arcade.

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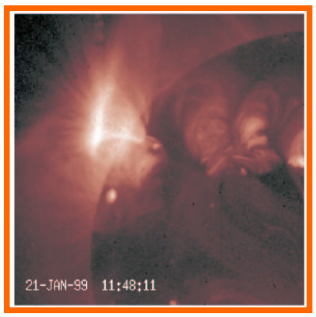
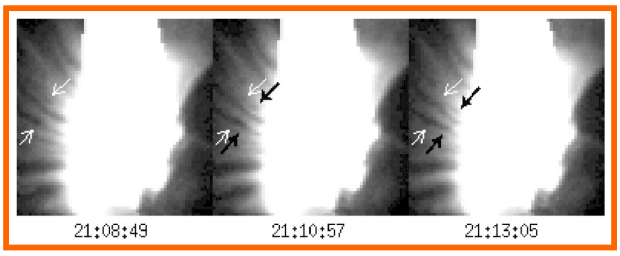
Observational Support for the Standard Model:

(2) Supra-Arcade Downflows in LDEs



Evidence for shrinking back of field lines following coronal reconnection



McKenzie & Hudson 1999

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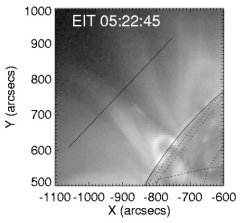
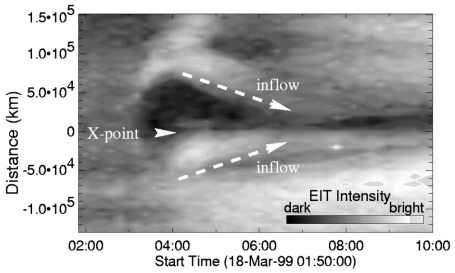
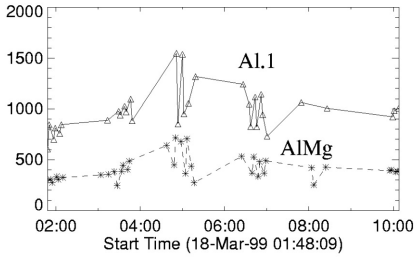
Observational Support for the Standard Model:

(3) A Reconnection Inflow

Yokoyama et al 2000







M_A(inflow) ~ 0.001-0.03

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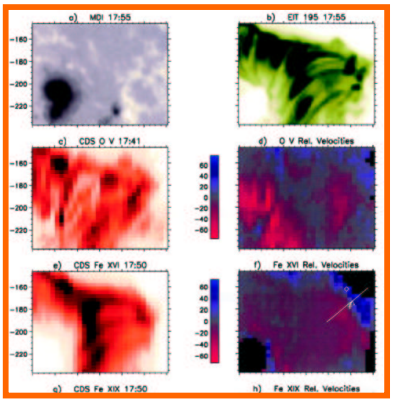
Observational Support for the Standard Model:

(4) chromospheric upflows and downflows



Particularly elegantly demonstrated by Czaykowska et al (1999) using CDS post-flare observations.

Blueshifts on outer part of arcade
Redshifts on inner part

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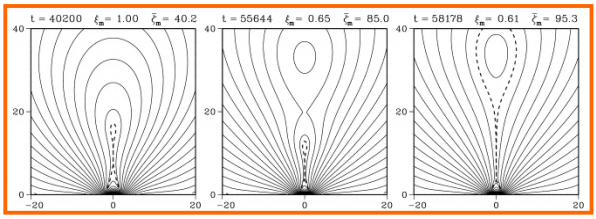
Driving the Standard Model

Within the standard model:

- A flare needs a reconnection region
- a reconnection region needs a current sheet (or neutral line/null)
- a current sheet needs an eruption of a flux rope

A large literature exists on the analytic and numerical modelling of the driving towards an ideal MHD eruption of a pre-flare arcade
- requires (a) antiparallel shear flows along neutral line or
(b) flow field convergence towards neutral line



Choe & Cheng 2000

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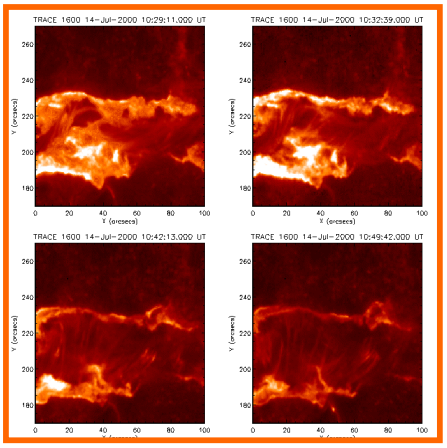
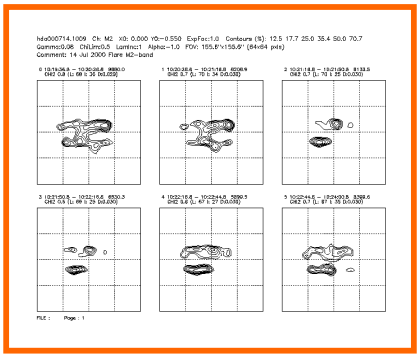
Sheared Field: Observations



Post-flare loops, initially highly sheared, become progressively less sheared



Location of HXR sources suggest that initial reconnection is on fields with high angle to neutral line (Masuda et al 2002)

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To Erupt or Not?

Many of the numerical simulations have problems in making flux ropes erupt and leave the solar surface

- a problem for understanding CMEs, but not so crucial for flares
- 2-ribbon flares may or may not show filament eruptions.

movie1 Filament clearly erupts to south west

movie 2 Filament moves up and sloshes about

movie3 Filament sucked under from LHS

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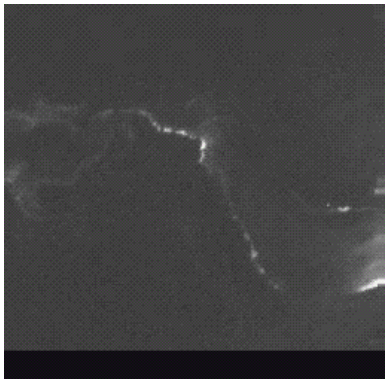
14 July 2000 Flare seen by TRACE

The 14-Jul-00 flare exhibited moving EUV ribbons (seen by TRACE), which spread apart as the flare progressed



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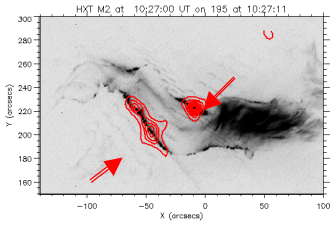
Generation of EUV Flare Ribbons

EUV ribbons could be produced by:
- Heating by energetic particles accelerated in flares (increased T ⇒ thermal Fe XI/XII)
- Impact excitations by energetic particles (non-thermal excitation)
- Thermal conduction along loops



From Fletcher & Hudson 2002

Comparing spatially-resolved HXR/EUV ⇒ particles responsible for EUV ribbons

Comparisons of UV/HXR *time* profile (e.g.Kane Frost & Donnelly, 1979, Woodgate et al.1983)
→ close time correlations (within 1s)
→ particle bombardment

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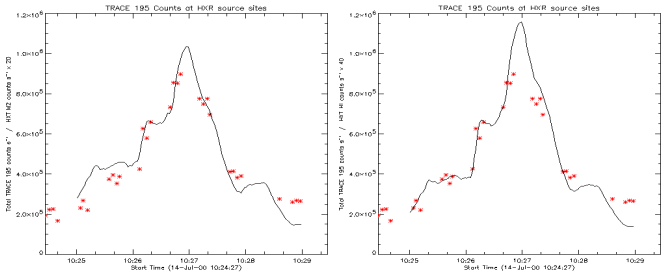
Sum normalised counts/second in small regions around the centroids of HXR emission



- EUV and HXR emissions track one another well
  consistent with particle excitation/heating
- Approximately linear relationship between HI/EUV
  consistent with particles
- Main peaks simultaneous to within 20s
- EUV falls off rapidly after peak
  expect a more Neupert-like profile in EUV if conductive heating

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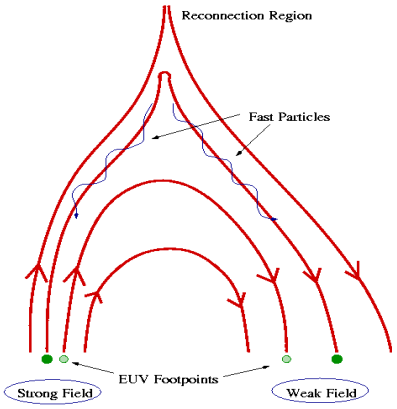
Ribbons and Field

As reconnection progresses in the corona, the footpoints of 'just reconnected' fieldlines are illuminated (by particles/ heat conduction) leading to the appearance of flare ribbons.

The footpoint ribbons sweep across the magnetic field



Predictions:

Footpoint ribbons move faster through weak field

Equal flux 'swept out' on either side of the neutral line

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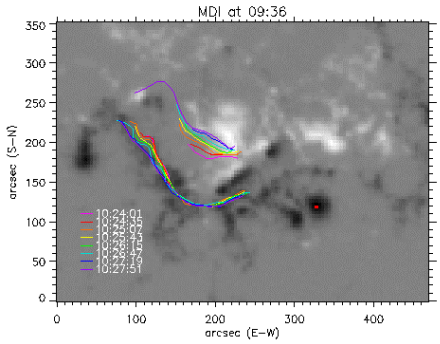
Movement of EUV ribbons



In some instances, ribbons move slowly through low field regions.

Footpoints in low B regions

Ribbons straighten out as they slow down.

Longitudinal fluxes swept out on both sides of the neutral line are not equal

Total longitudinal flux swept out by ribbons (10^{20} Mx)

Time after 10 UT	25:07-26:15	26:15-27-19	25:19-28:58	25:07 - 28:58
NORTH	-4.1 ± 0.5	-3.3 ± 0.4	-3.3 ± 0.3	-11.2 ± 0.5
SOUTH	1.2 ± 0.4	2.2 ± 0.6	2.4 ± 0.6	5.9 ± 1.6 or 6.2 ± 1.4

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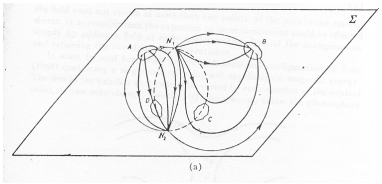
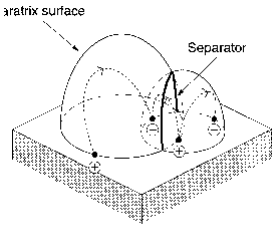
3-D fields

In reality, one must take into account the actual distribution of magnetic sources in the photosphere and construct the 3-D field - even in the apparently axisymmetric case of 2-ribbon flares

Here there is also a growing literature (Demoulin, Priest, Mandrini, Amari, Longcope, Gorbachev, Somov…)



Sweet (1959) demonstrated presence of nulls and separators in multipolar field



In 3-d this gives separatrix surfaces and their intersections, separators (from Priest & Schrijver 2000)

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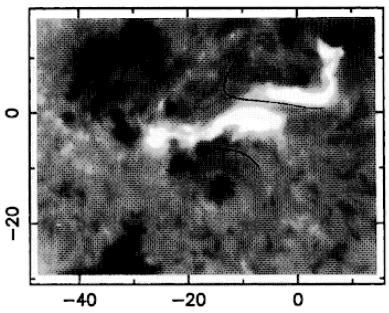
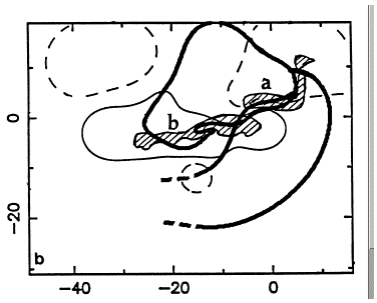
E.g. Mandrini et al 1995

(from a series of papers with Demoulin and collaborators)



Hα-0.6A image showing 2-ribbon event



Linear FFF extrapolation from photospheric vector field showing intersection of separator with source plane

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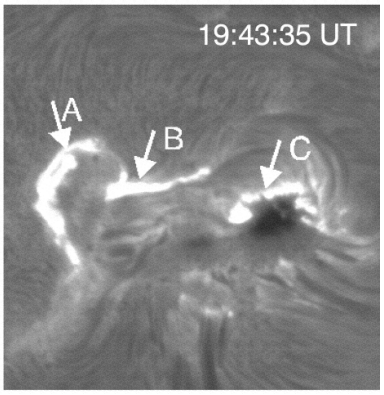
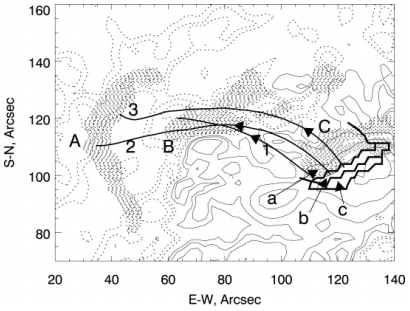
Yurchyshyn et al.





Using FF extrapolation fit to SXT data, the authors find 3 separate flux systems

- interaction leads to excitation of flare ribbons

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Concluding Questions - in the light of new observations and theory

Can UV/EUV observations tell us anything new about accelerated particles?

Mismatch in magnetic flux - instrumental or 'physical'

Can energy be stored long term in localised current sheets, or do flares always require driving and an MHD instability

Is it meaningful to maintain a distinction between compact and 2-ribbon flares - is it all a matter of topology?

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