

# Slné erupcie

The image depicts a powerful solar eruption, likely a coronal mass ejection or a solar flare. It features a dark, swirling structure with a bright, glowing core. The overall color palette is dominated by deep oranges, yellows, and reds, set against a black background. The text 'Slné erupcie' is overlaid in white, bold, sans-serif font.

# Erupcia

- Jav, pri ktorom dochádza k náhlemu a „krátkodobému“ zvýšeniu intenzity elektromagnetického žiarenia v širokej oblasti jeho spektra, k urýchľovaniu a vyvrhnutiu elektricky nabitých častíc, k ohrevu a usmerneným pohybom plazmy
- Je prejavom magnetickej aktivity hviezd
- Pozorujeme ju v atmosfére hviezdy (Slnka)

## Fázy vývoja erupcie

- Pred erupčná – prekursori – iba niekedy (zjasnene v EUV alebo RTG oblasti - minúty ale aj hodiny).
- Počiatková (impulzná) – prudký nárast toku mäkkého RTG žiarenia; výskyt pulzov v oblasti tvrdého RTG a mikrovlnného žiarenia; je kratšia a má strmší priebeh ako nasledujúca graduálna fáza (10 - 20 min.).
- Graduálna – tok mäkkého RTG žiarenia postupne klesá, vytvárajú sa po-erupčné slučky (až niekoľko hodín).

# Erupcia – používané klasifikácie:

- **Podľa maxima toku mäkkého RTG žiarenia** (1 – 8 Å) nameraného v oblasti Zeme:

trieda:	<b>B</b>	$F \in \langle 10^{-7}, 10^{-6} \rangle \text{ W.m}^{-2}$
	<b>C</b>	$F \in \langle 10^{-6}, 10^{-5} \rangle \text{ W.m}^{-2}$
	<b>M</b>	$F \in \langle 10^{-5}, 10^{-4} \rangle \text{ W.m}^{-2}$
	<b>X</b>	$F \geq 10^{-4} \text{ W.m}^{-2}$

napr. pre erupciu s označením M5.8 bude:  $F = 5.8 \times 10^{-5} \text{ W.m}^{-2}$

- **Podľa veľkosti plochy v H- $\alpha$**  (v  $10^6$  plochy hemisféry):

trieda:	<b>S</b>	$\leq 200$
	<b>1</b>	200 – 500
	<b>2</b>	500 – 1200
	<b>3</b>	1200 – 2400
	<b>4</b>	> 2400

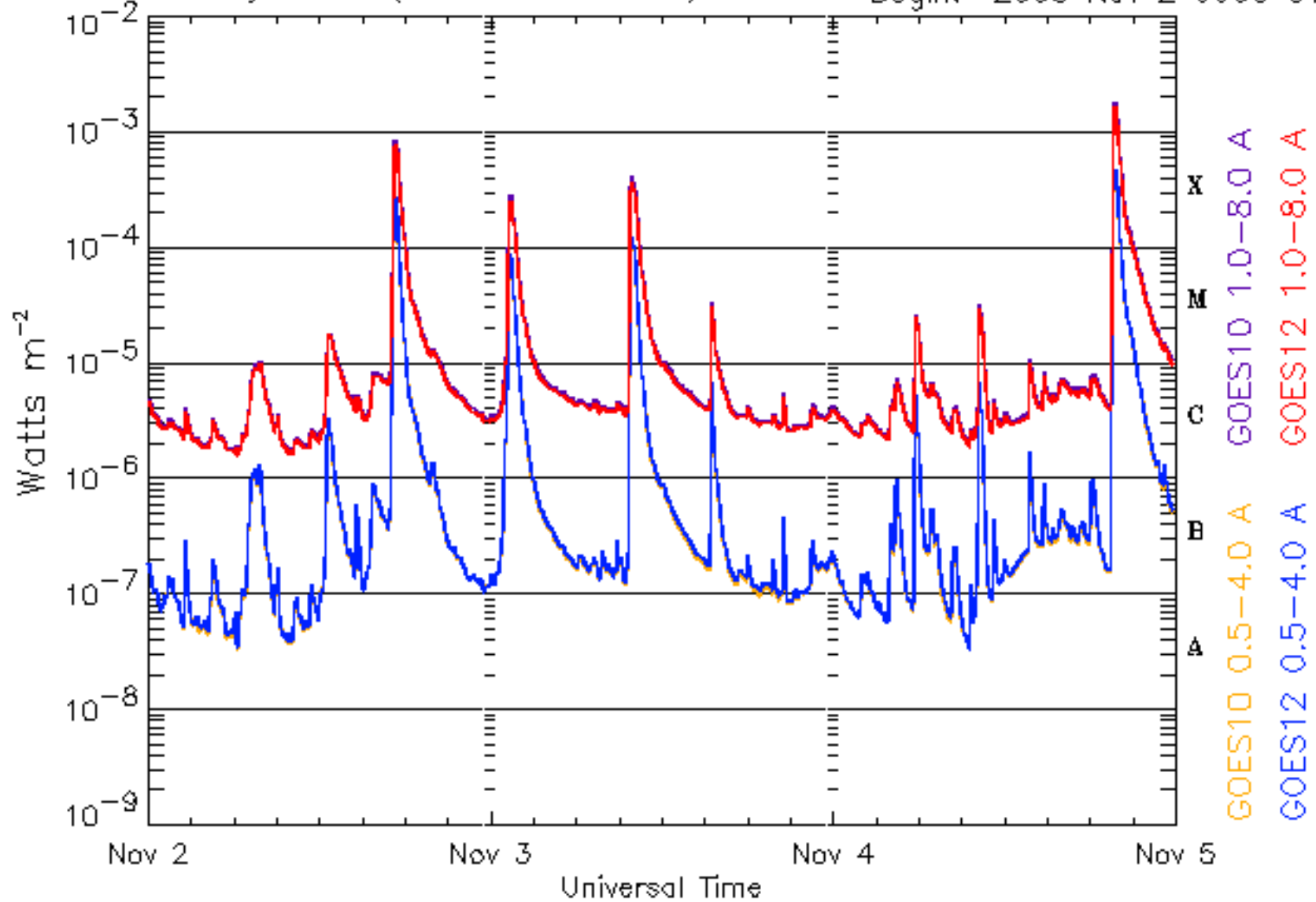
trieda + prípona *f*, *n* alebo *b* (subjektívne):

*f* – faint (slabé), *n* – normal, *b* - brilliant (žiarivý)

<http://sidc.oma.be/edu/classification.html>

# GOES Xray Flux (5 minute data)

Begin: 2003 Nov 2 0000 UTC



Updated 2003 Nov 4 23:56:03 UTC

NOAA/SEC Boulder, CO USA

# Zdroj energie erupcií

- pri veľkých erupciách sa uvoľní energia až  $3.0E+25$  J
- jej zdrojom je magnetické pole, uvoľniteľná energia  
 $W_{\text{flare}} = B_{\text{cor}} - B_{\text{pot}}$ ,  
magnetický "šmyk", skrútené siločiarly mgn. poľa,  
elektrické prúdy, vysoká komplexnosť mgn. poľa  
skrútenie slučky dĺžky 50 Mm, hrúbky 10 Mm s mgn. poľom 50 G o uhol  $2\pi$   
má uvoľniteľnú energiu  $3.0E+23$  J, čo je dostatočné pre malú erupciu
- energia poľa je dodávaná pohybmi fotosférických ukotvení  
slučiek, rotáciou a vynáraním sa mgn. poľa spod fotosféry
- tieto pohyby zároveň pôsobia aj ako "spúšťací"  
mechanizmus



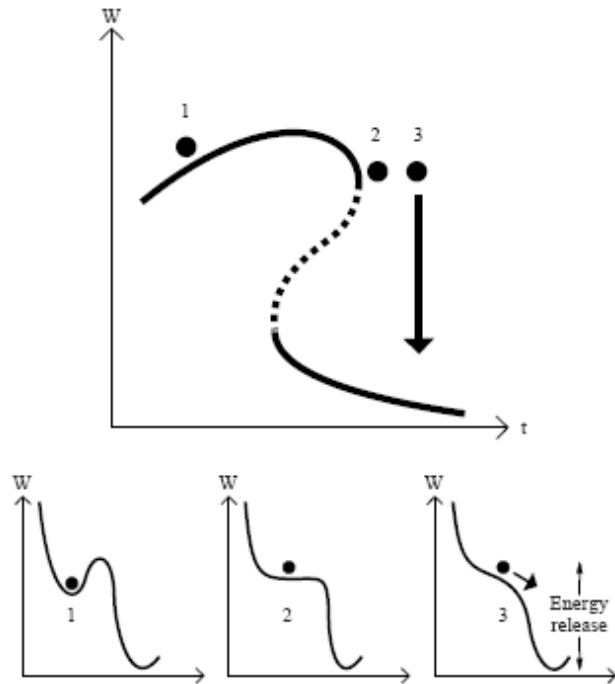
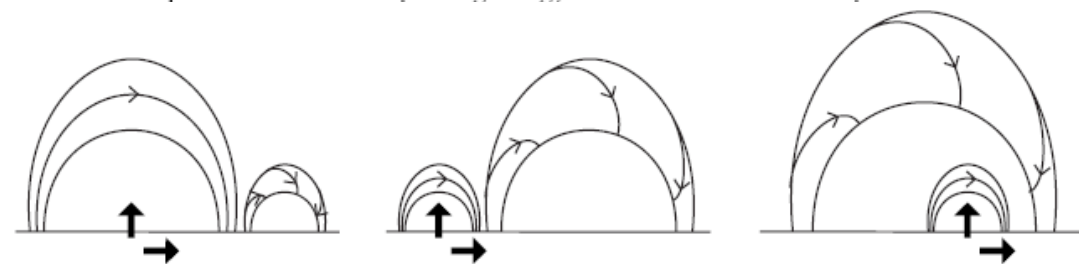
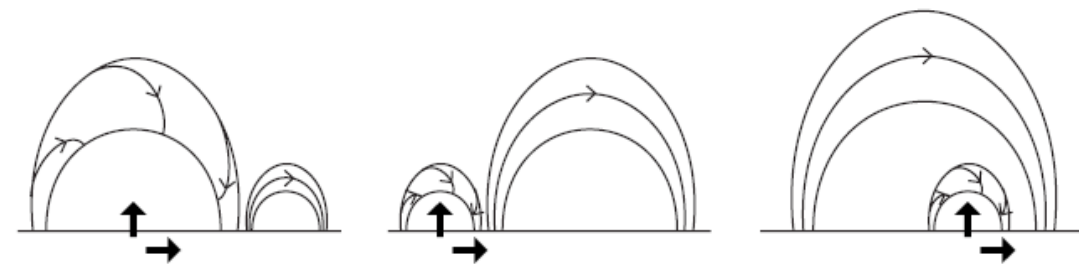


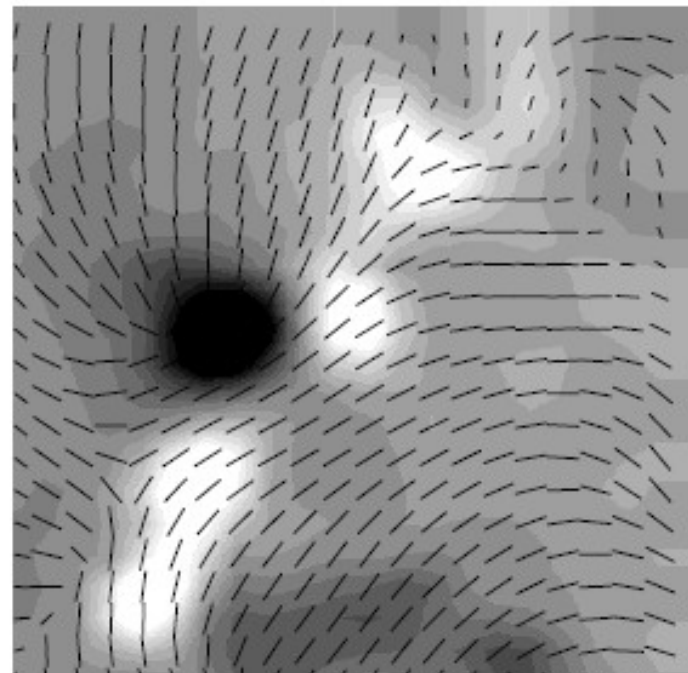
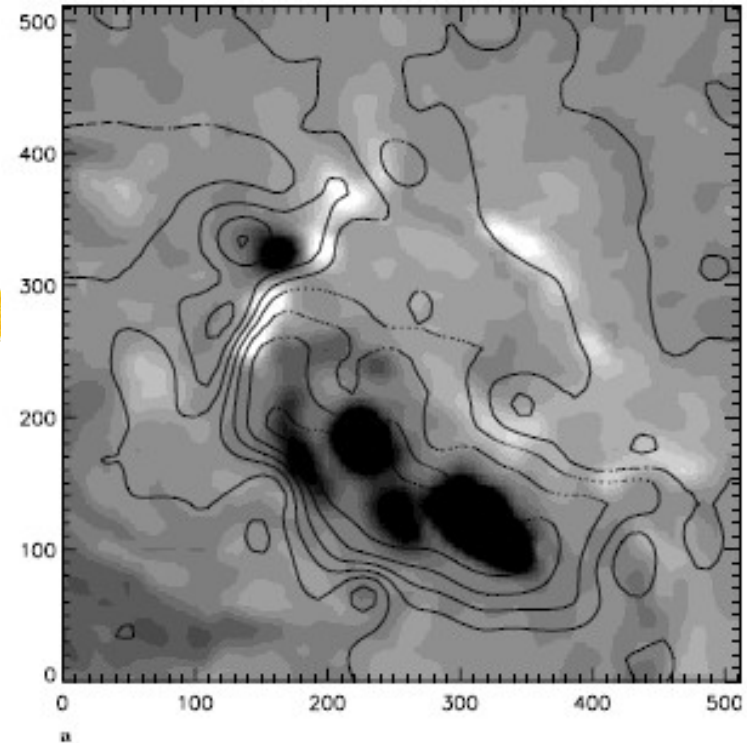
Fig. 11. The slow evolution (above) of the energy  $W$  as a function of time from state 1 to 2 and then to a state 3 of nonequilibrium. The corresponding energy wells are indicated in the panels below.



a



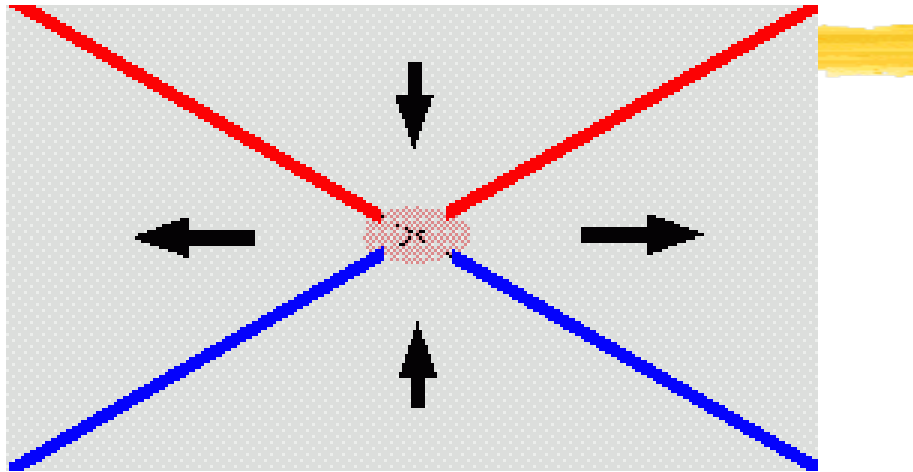
b



# Magnetická topológia a rekonexia:

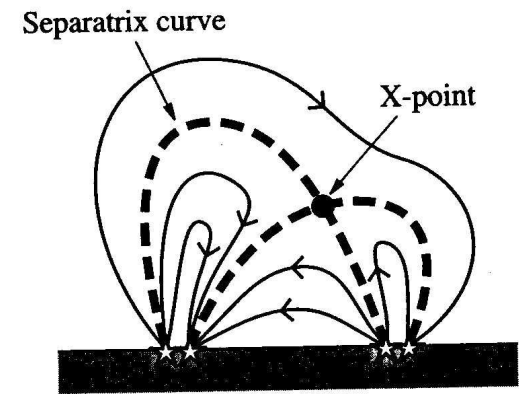
- Magnetická topológia sa zaoberá štúdiom konektivity rôznych tokových systémov magnetického poľa v aktívnych oblastiach – indikuje miesta, v ktorých môže dôjsť k rekonexii (uvoľneniu magnetickej energie)
- Spomínané klasifikácie erupcií však nehovoria veľa o fyzikálnej podstate erupcií – výhodnejšia je klasifikácia z hľadiska topológie magnetického poľa
- **uzavreté/impulzné** – kompaktné
- **eruptívne/dynamické** – v počiatkovej fáze sú magnetické siločiarly uzavreté, počas ďalšieho erupcie vývoja sa „otvorí“, bývajú spojené s CME

# Rekonexia

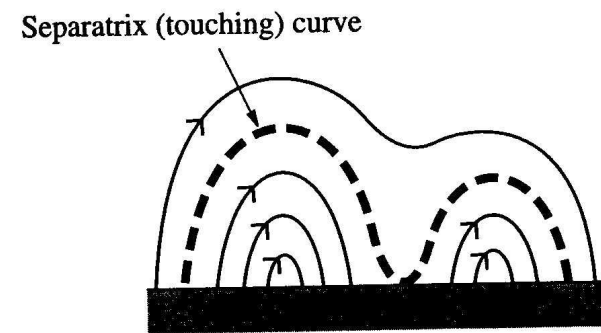


**Separatrix** – oddeľuje od seba dva rôzne magnetické systémy – diskontinuita v konektivite

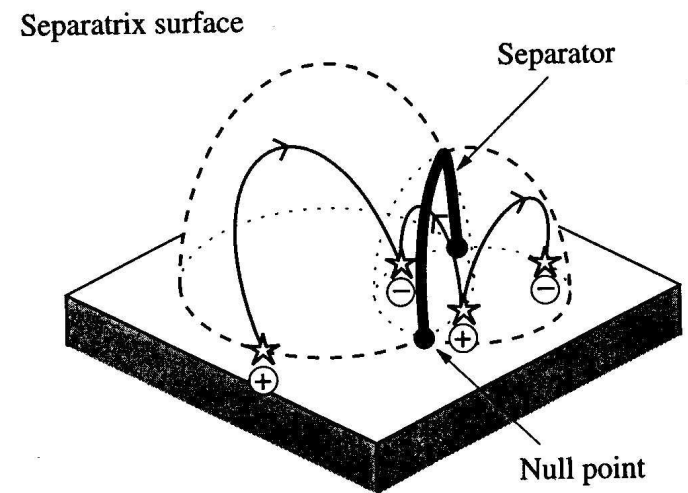
**Difúzna oblasť** – difúzia magnetického poľa – ohmická disipácia elektrického prúdu



(a)



(b)



(c)



# 2-D rekonexia

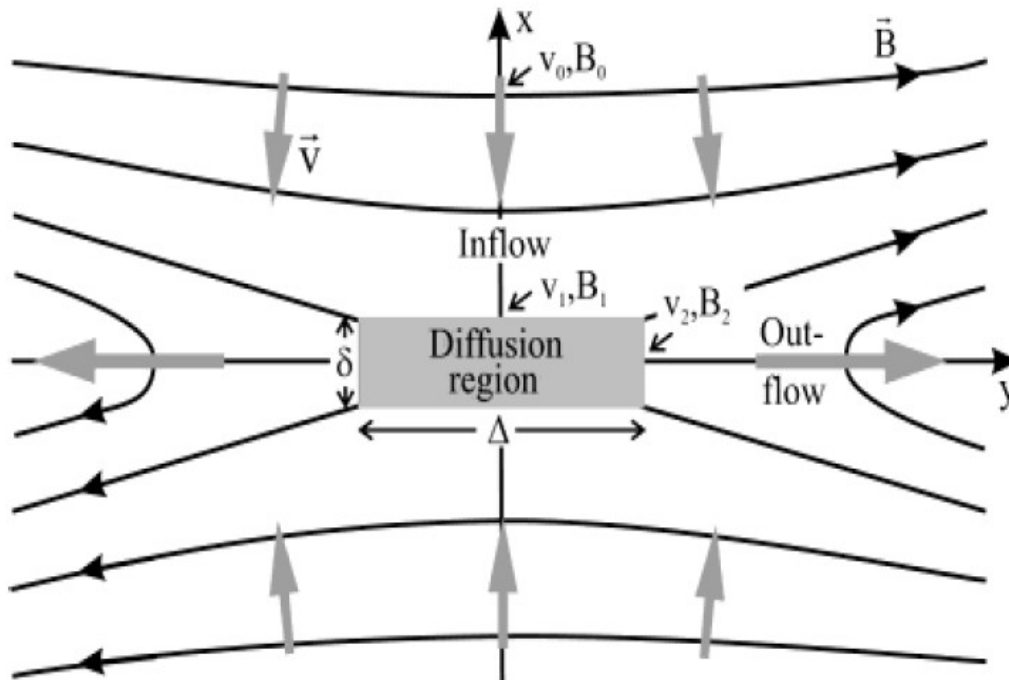


Figure 10.1: Basic 2D model of a magnetic reconnection process, driven by two oppositely directed inflows (in x-direction), which collide in the diffusion region and create oppositely directed outflows (in y-direction). The central zone with a plasma- $\beta$  parameter of  $\beta > 1$  is called the diffusion region (grey box) (Schindler & Hornig 2001).

Sweet-Parker model

$\Delta \gg \delta$ , stacionárny,  
problém: nízka rýchlosť,  
škála  $\sim 4\pi\sigma\delta\Delta$

Petschek model

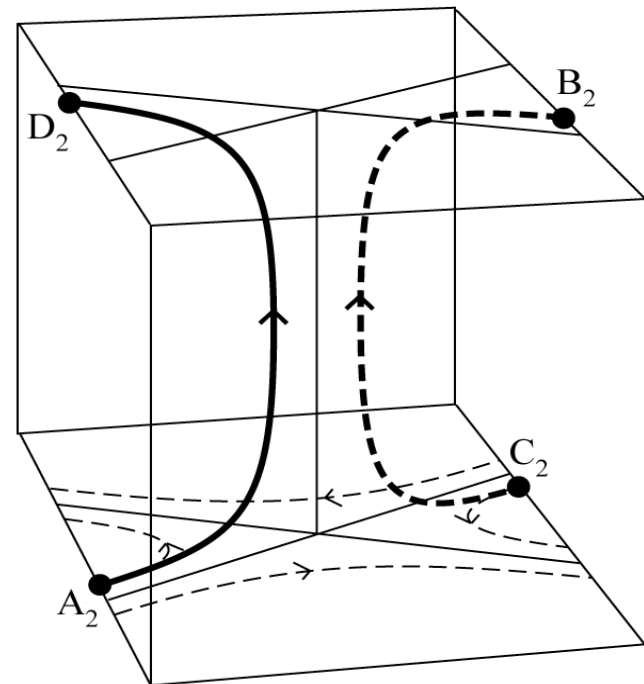
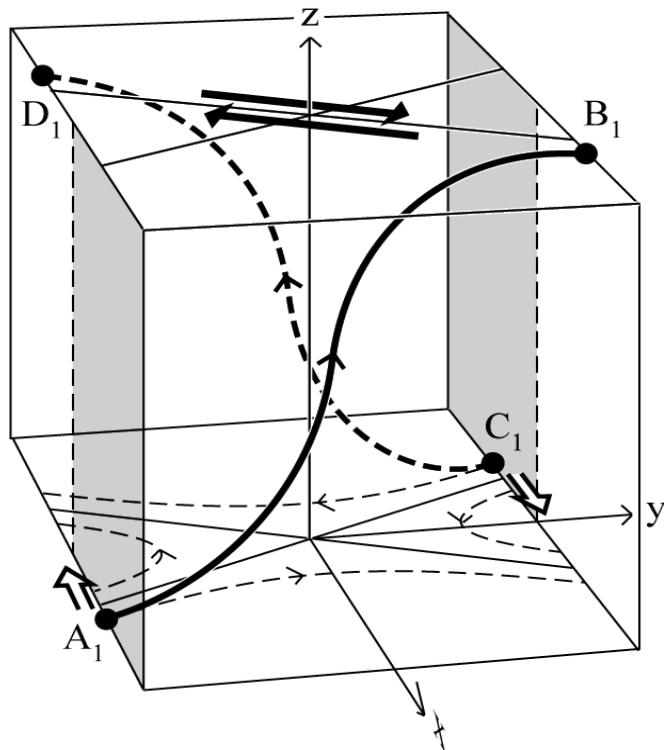
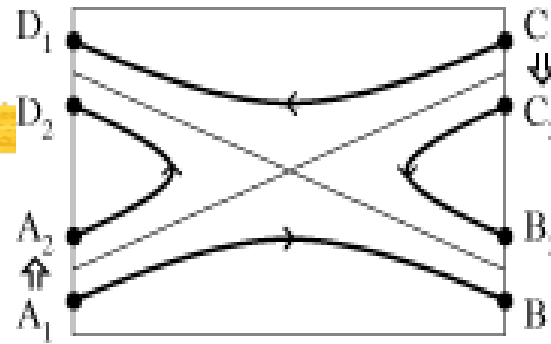
$\Delta \sim \delta$ , stacionárny, vyššia  
rýchlosť rekonexie

z nich sú odvodené ďalšie  
vylepšené nestacionárne 2-D  
modely, ktoré využívajú aj  
rôzne druhy nestabilit, pri  
ktorých sa vytvoria tzv.  
magnetické "ostrovy".

Elektrická vodivosť v plazme  
môže poklesnúť vďaka  
turbulencii, ktorá generuje  
pole elektrostatických vln –  
zmenšenie strednej voľnej  
dráhy – zníženie vodivosti.  
Nestačí, potrebné drastické  
zmenšenie difúznej oblasti.

# 3-D rekonexia

$B_z \neq 0$



# Modely erupcie/ CME

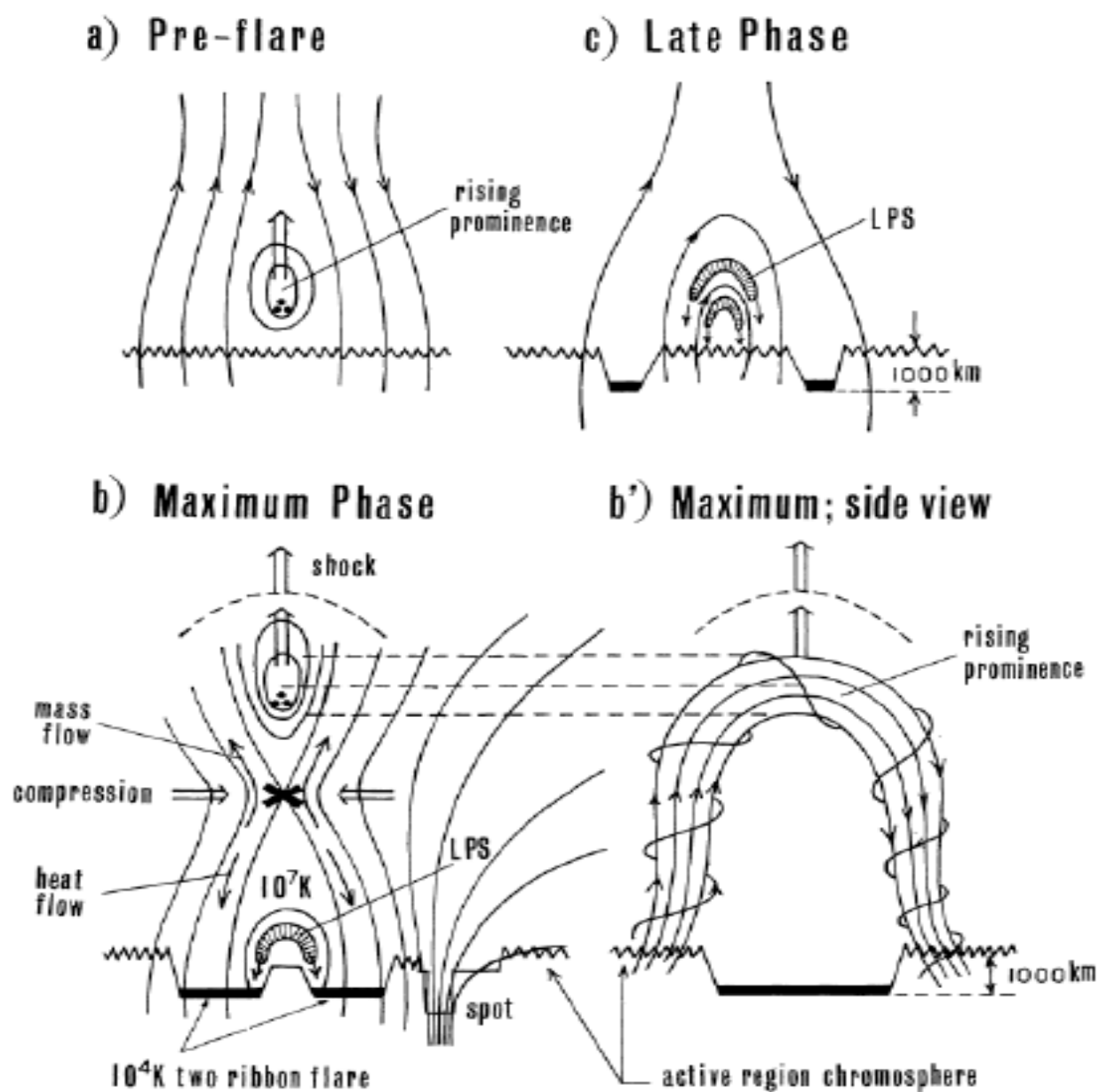


Figure 10.20: Temporal evolution of a flare according to the model of Hirayama (1974), which starts from a rising prominence (a), triggers X-point reconnection beneath an erupting prominence (b), shown in sideview (b'), and ends with the draining of chromospheric evaporated, hot plasma from the flare loops (c) (Hirayama 1974).

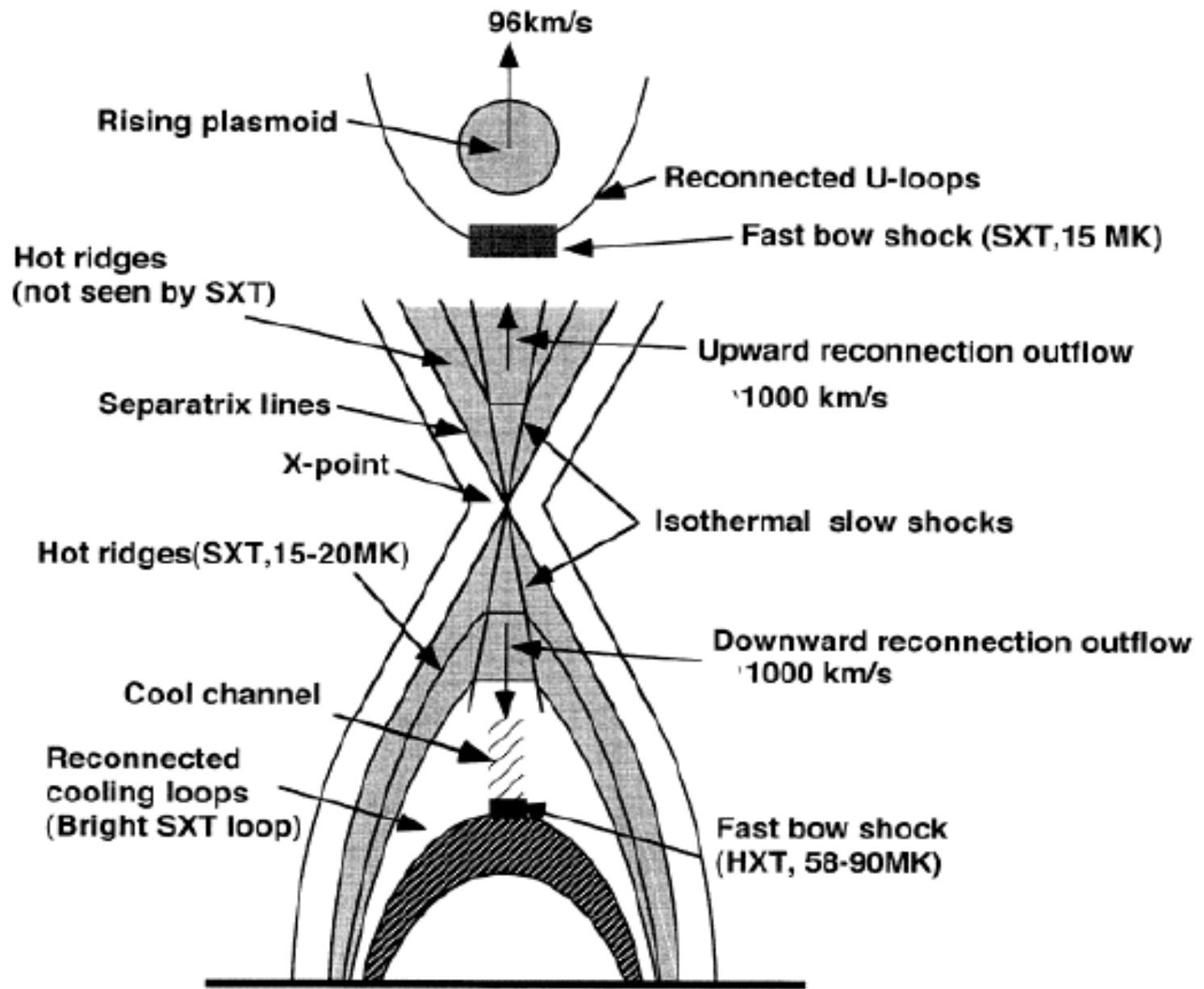
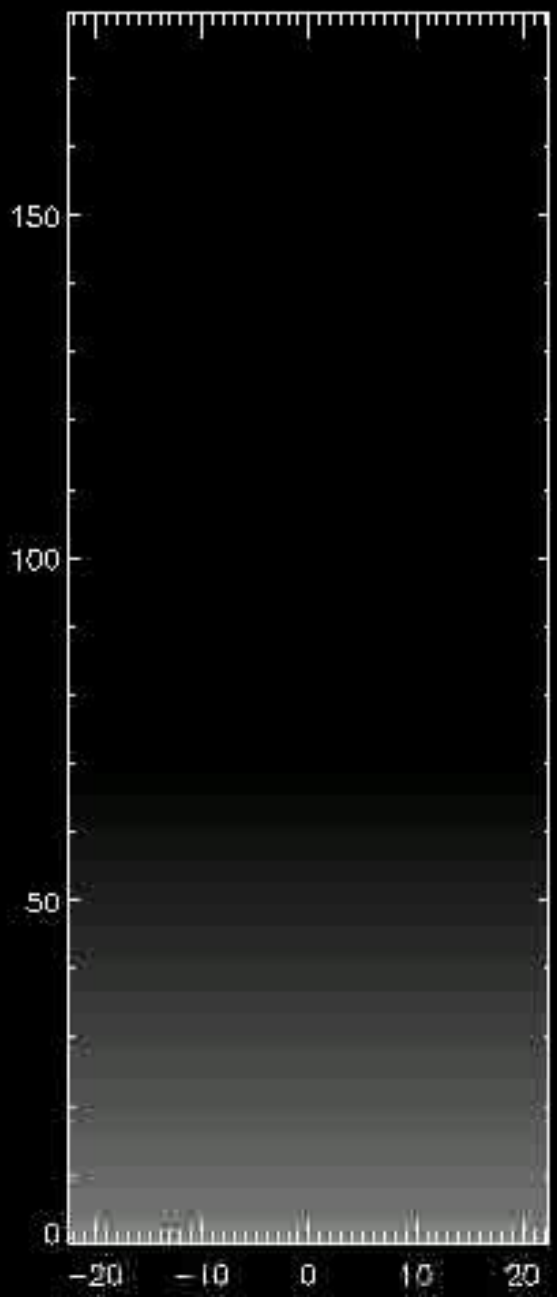
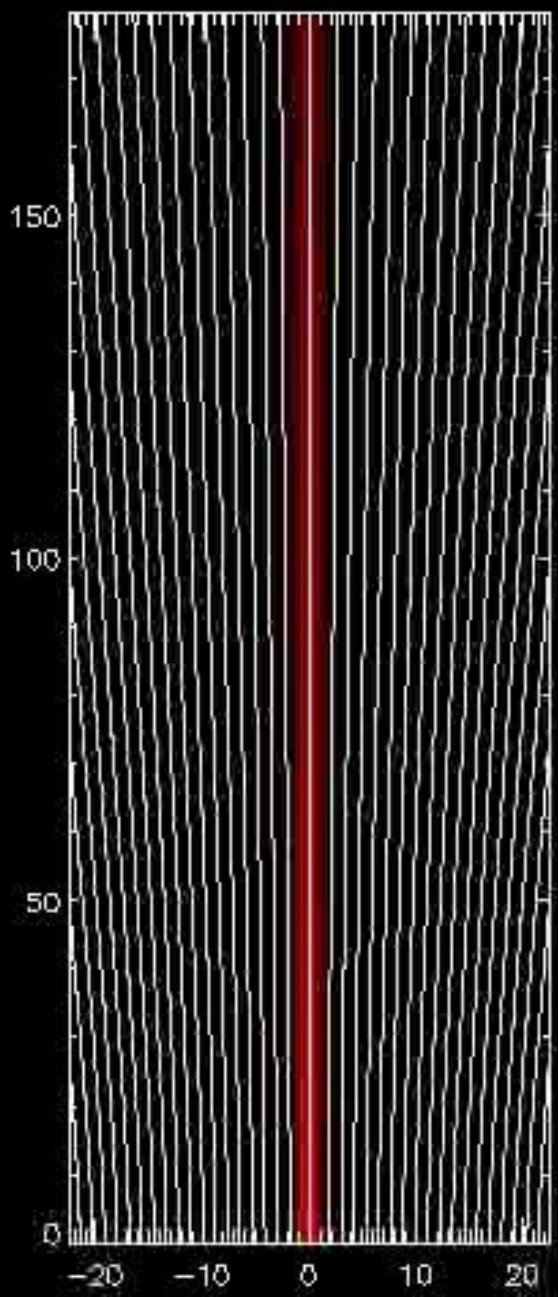
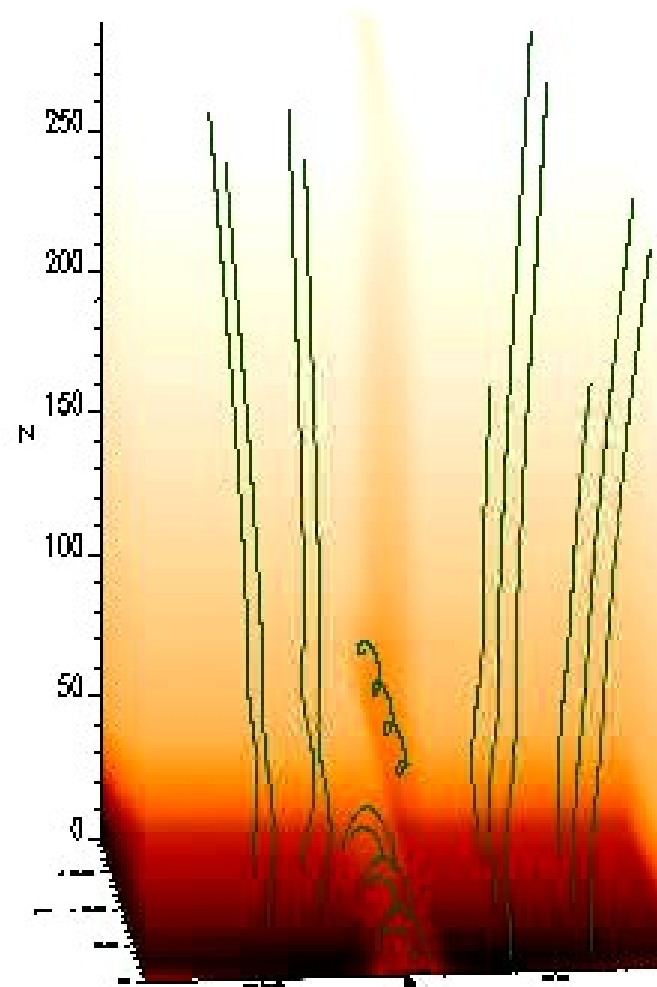


Figure 10.21: Elaborate version of the standard 2D X-type reconnection model that also includes the slow and fast shocks in the outflow region, the upward-ejected plasmoid, and the locations of the soft X-ray bright flare loops (Tsuneta 1997).

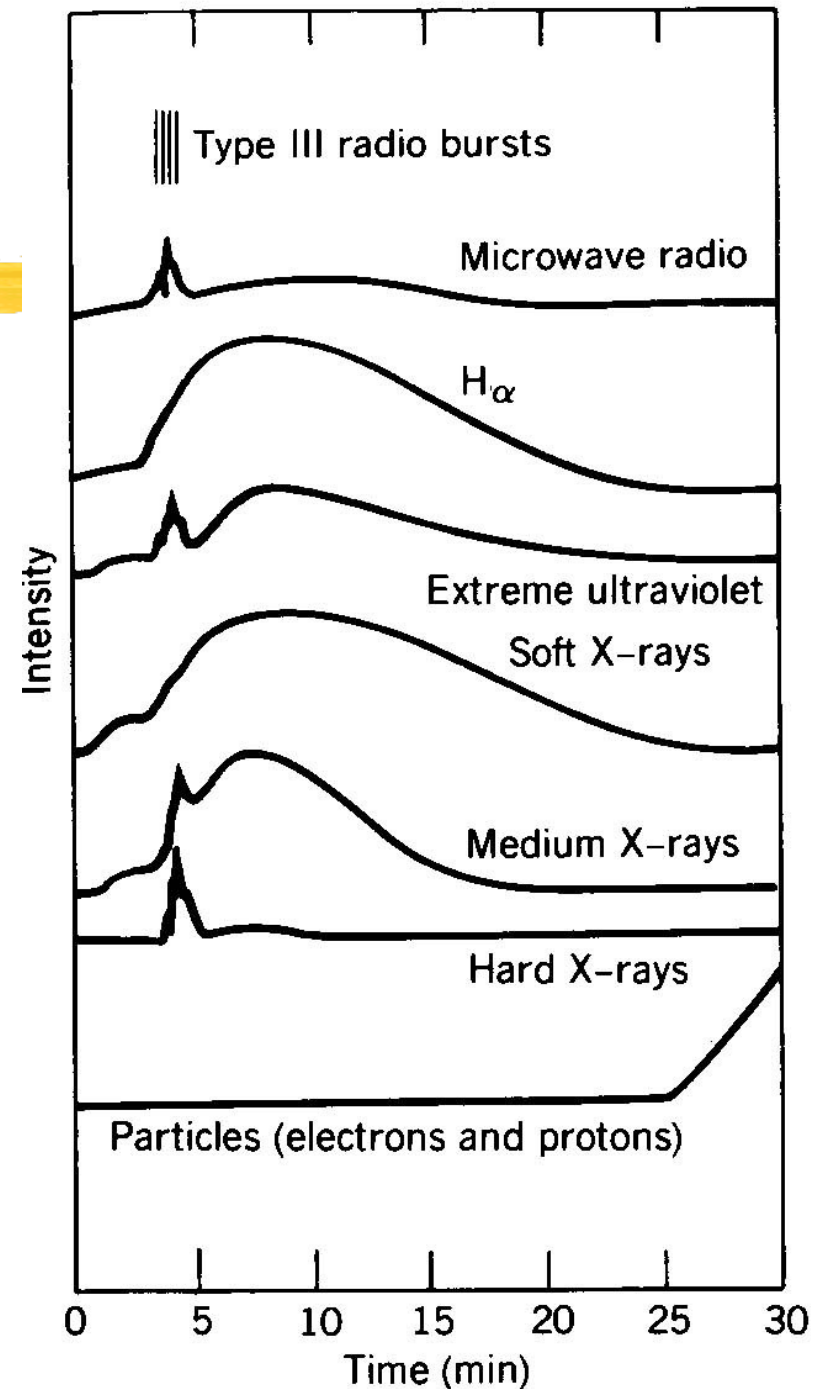


$t=200.0 \tau_A$

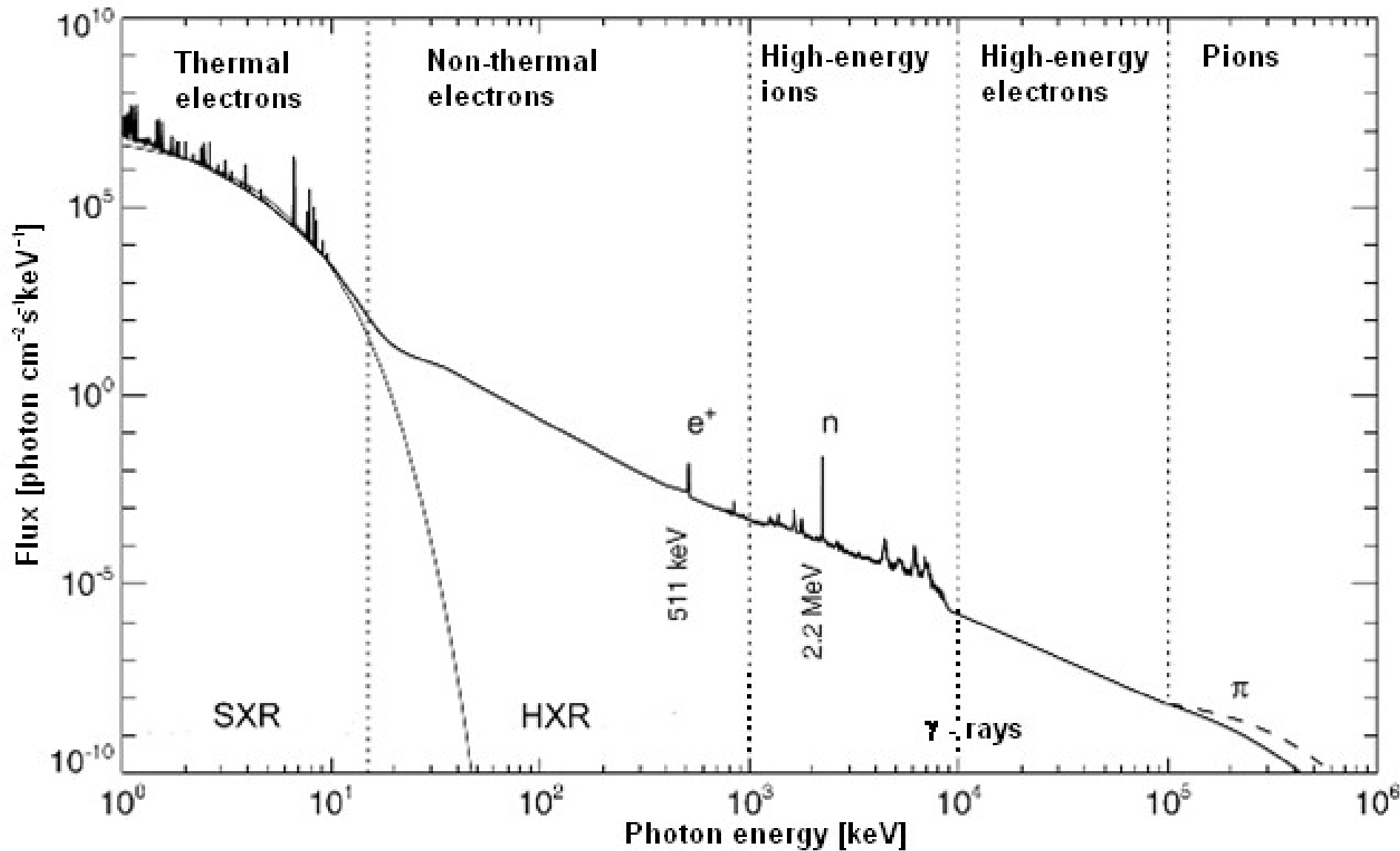


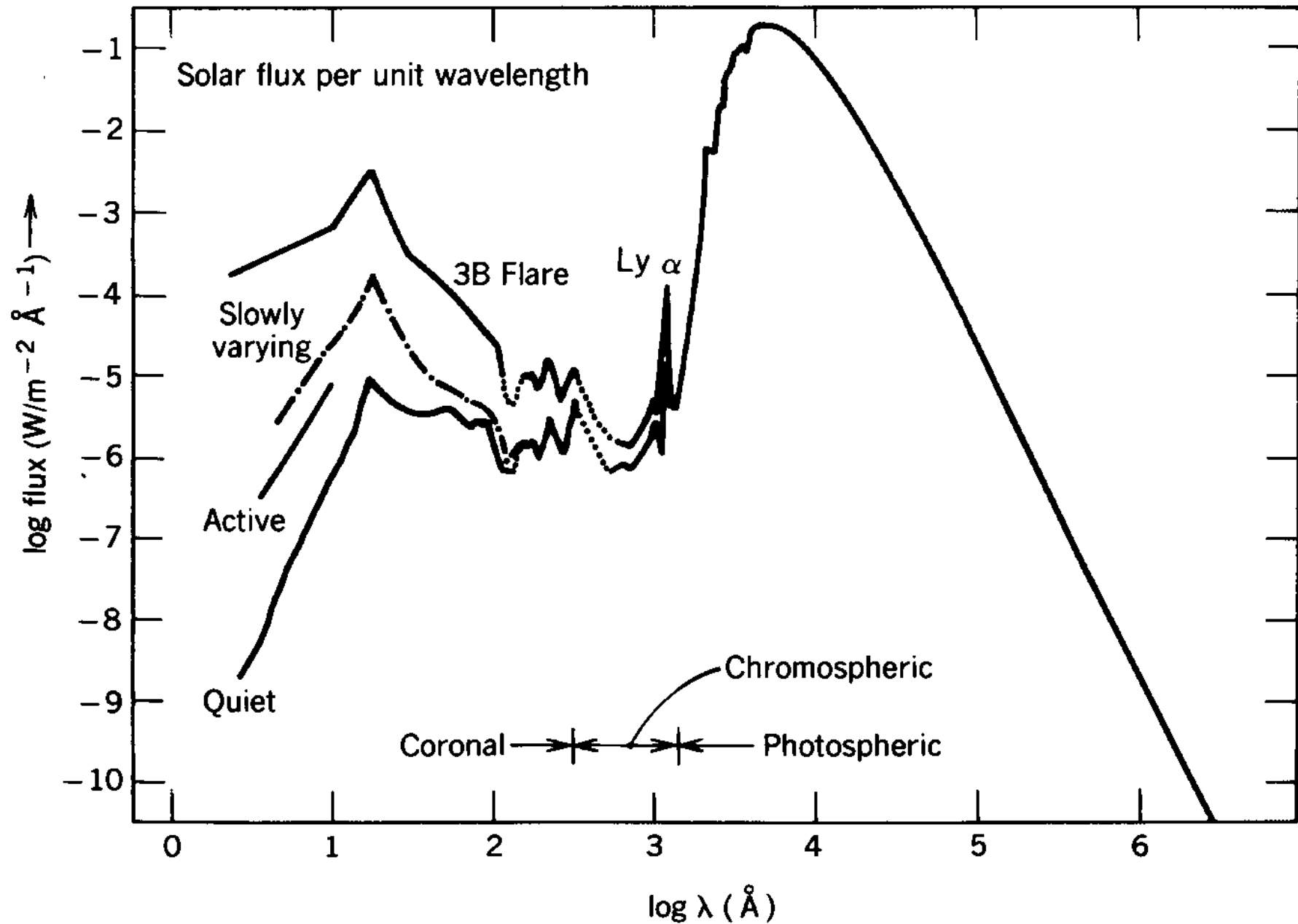


# Časový vývoj emisie žiarenia počas slnečnej erupcie



# Flare Spectrum (Continuum)

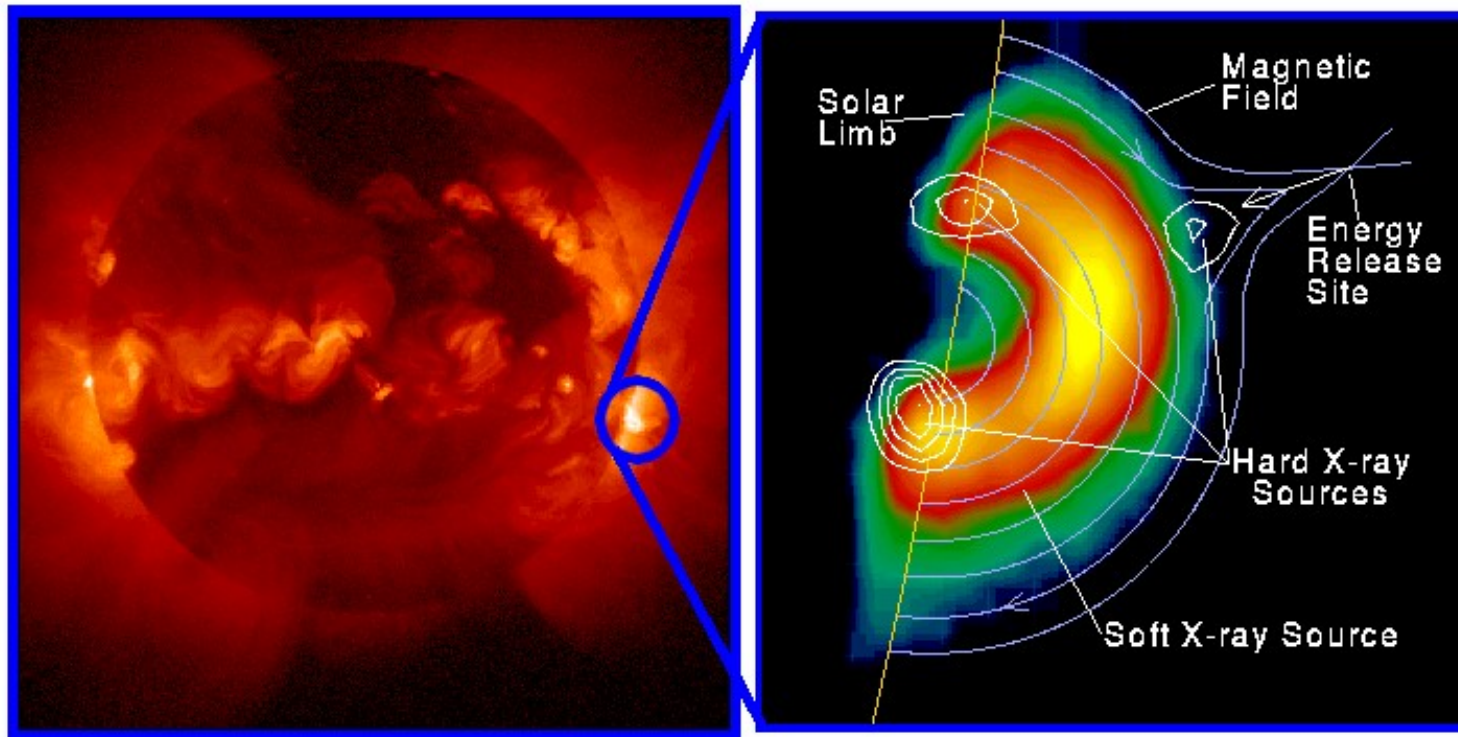
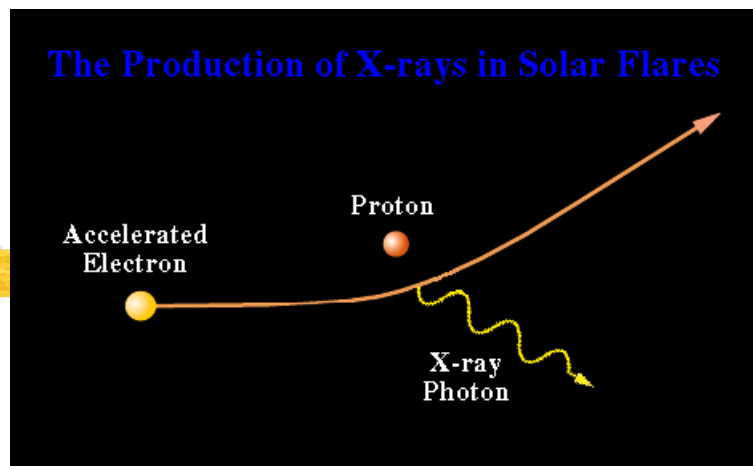




**Fig. 10-12** Enhancement of the solar spectrum at short wavelengths by a large flare. Adapted from E. Smith and D. Gottlieb. *Space Sci. Rev.*, **16**, 771 (1974).

# RTG žiarenie

Poskytuje najlepšiu informáciu o tom, kde sa v erupcii uvoľňuje energia



Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

X-Ray Flux (photons  $\text{cm}^{-2} \text{s}^{-1} \text{arcsec}^{-2} \text{keV}^{-1}$ )

Photon Energy  $\omega_{\text{ph}} = 12 \text{ keV}$

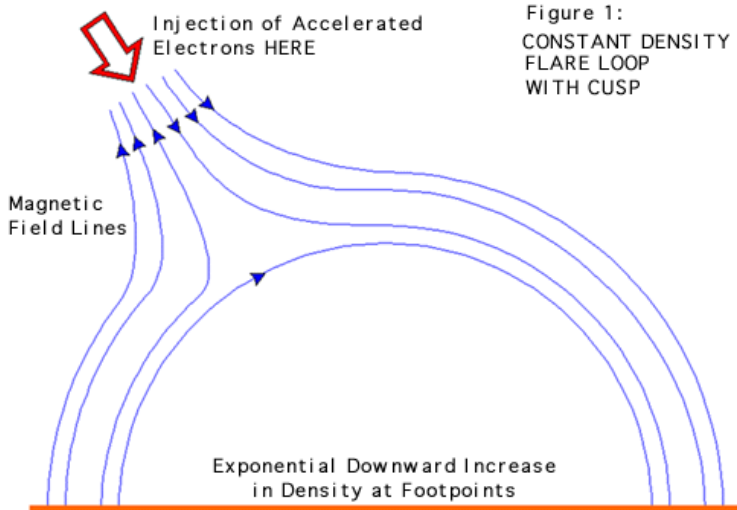
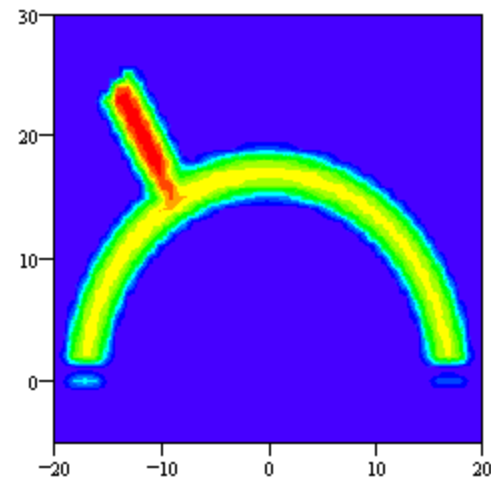
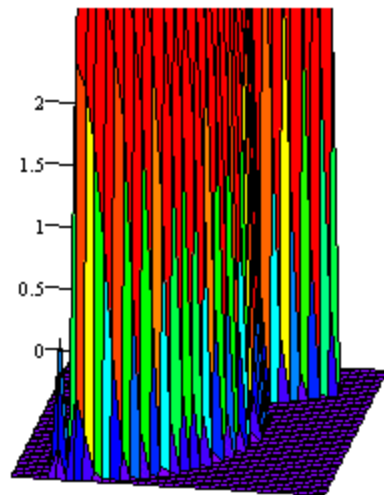


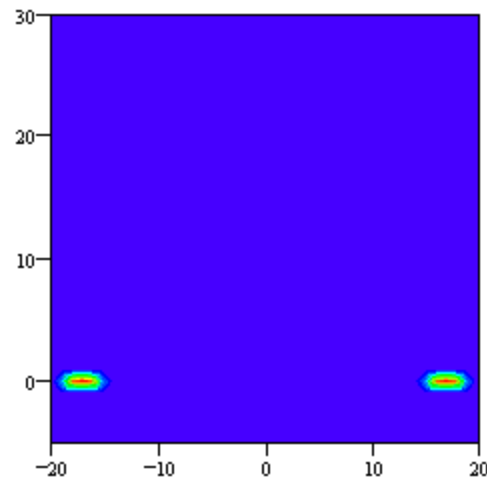
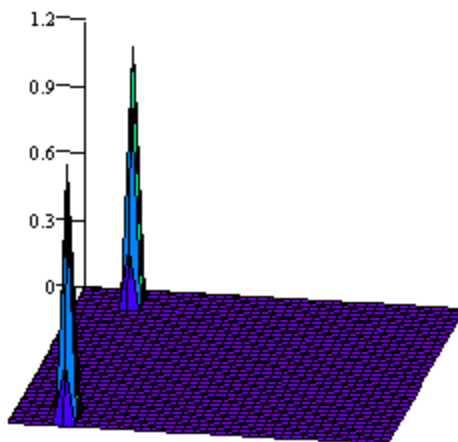
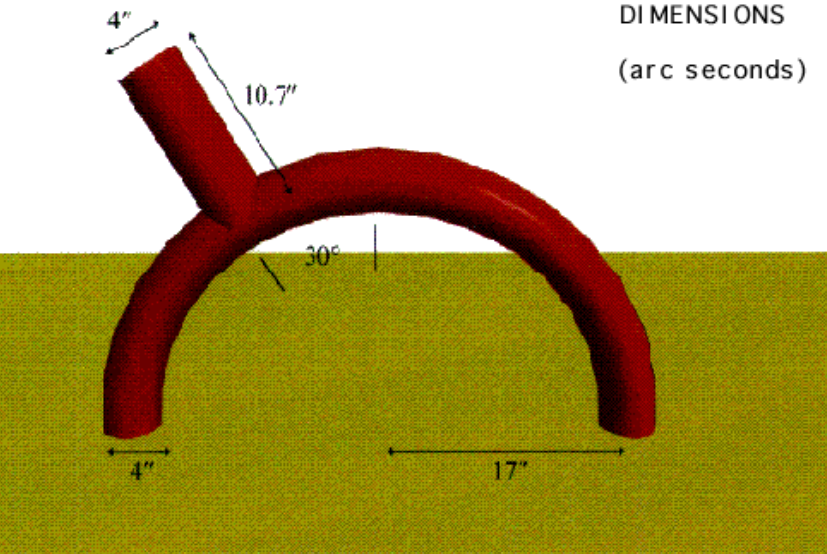
Figure 1:  
CONSTANT DENSITY  
FLARE LOOP  
WITH CUSP



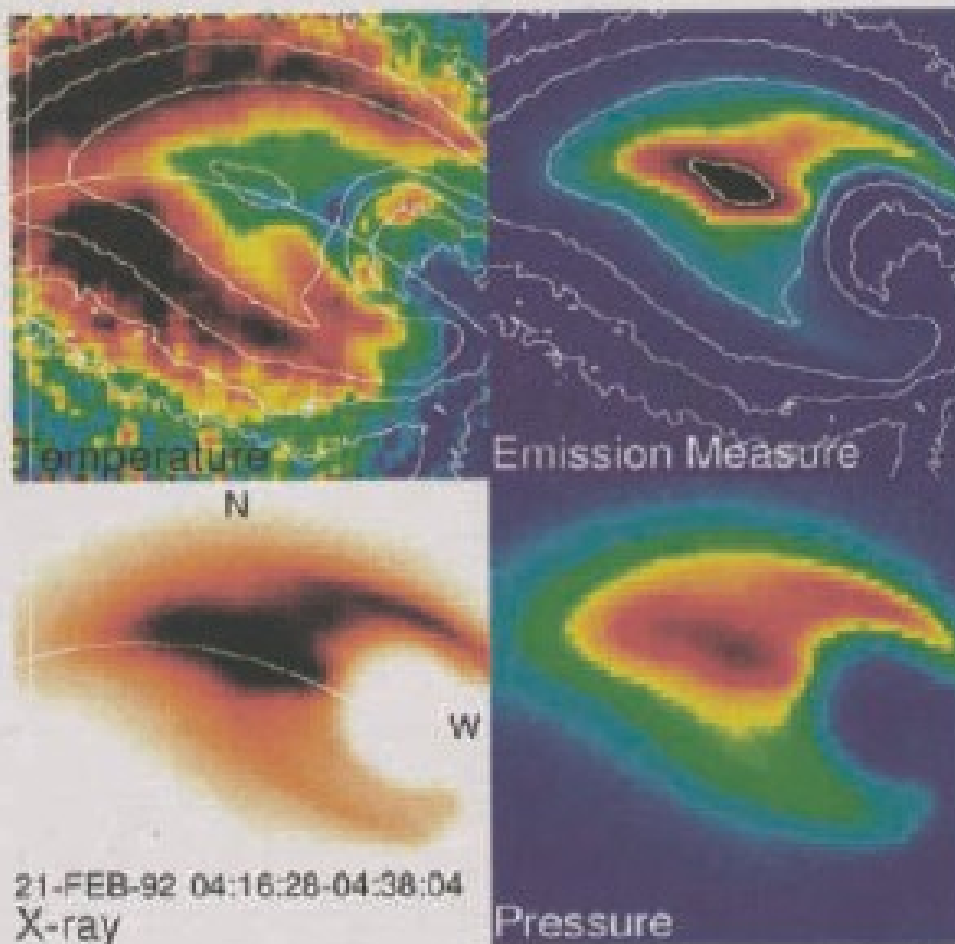
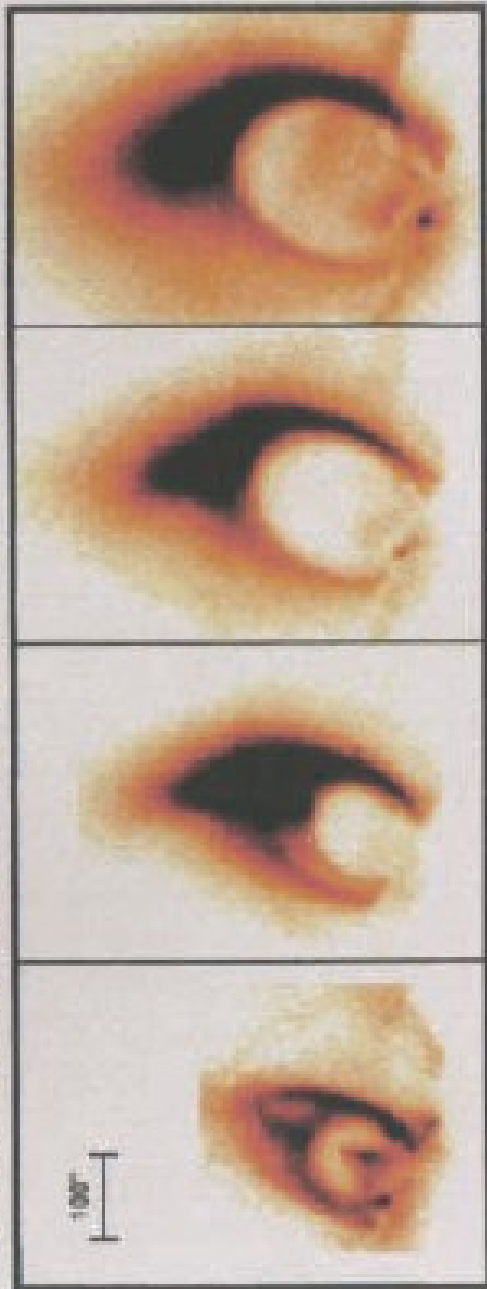
X-Ray Flux at 30 keV (photons  $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1} \text{arcsec}^{-2}$ )

Plasma Density:  $n_e = 1 \cdot 10^9 \text{ cm}^{-3}$

Figure 2:  
MODEL LOOP  
DIMENSIONS  
(arc seconds)



21-FEB-1992 Flare SXT Image Filter : Al.1



T(MK)

11

8

6

Pressure  
(dyn/cm<sup>2</sup>)

60

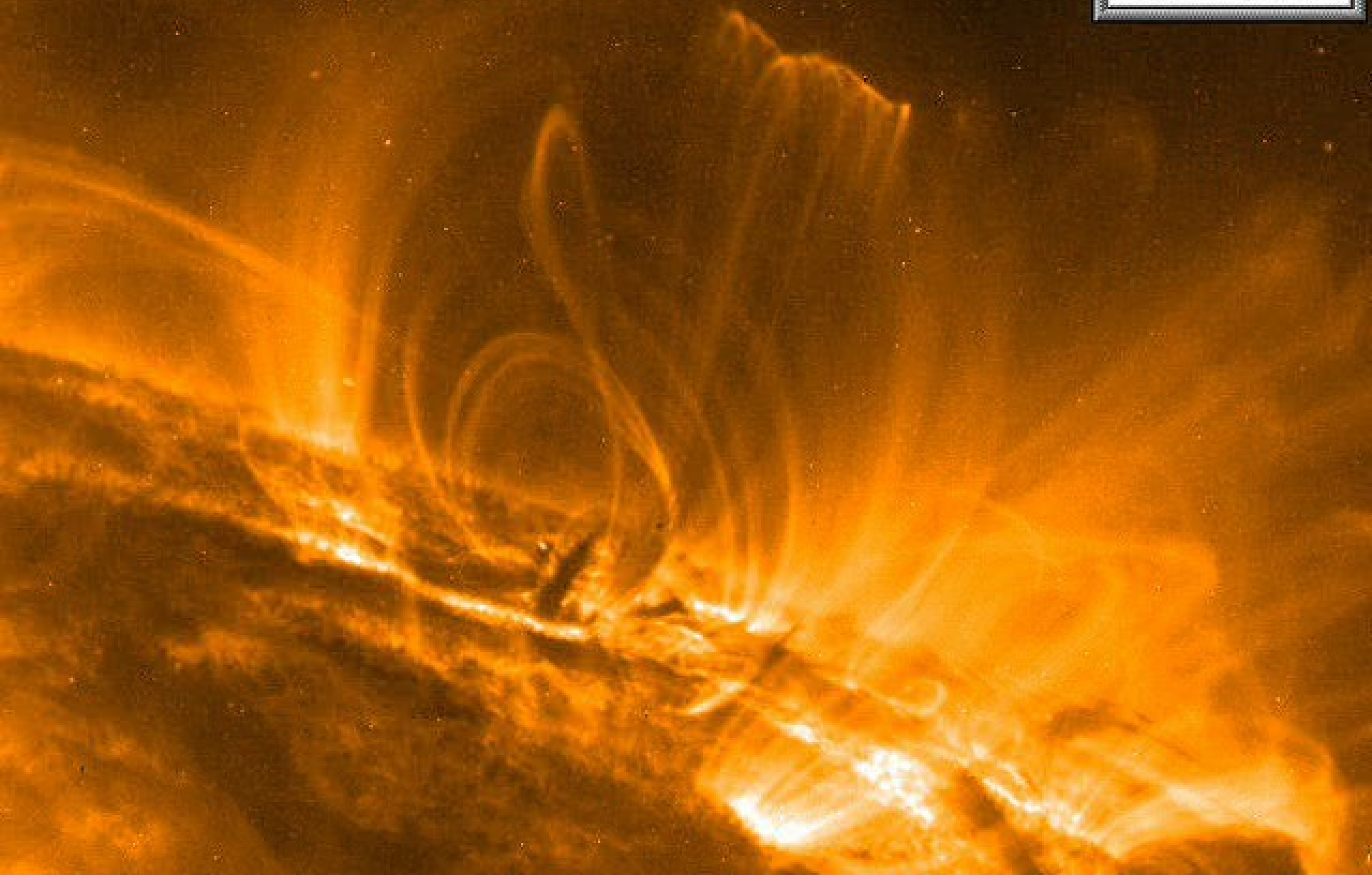
30

1

Fig. 46. The temperature and pressure structure in the Tsuneta flare (Tsuneta et al., 1992)



2001-Apr-15  
13:05:26  
dt = 60.1



# EUV žiarenie

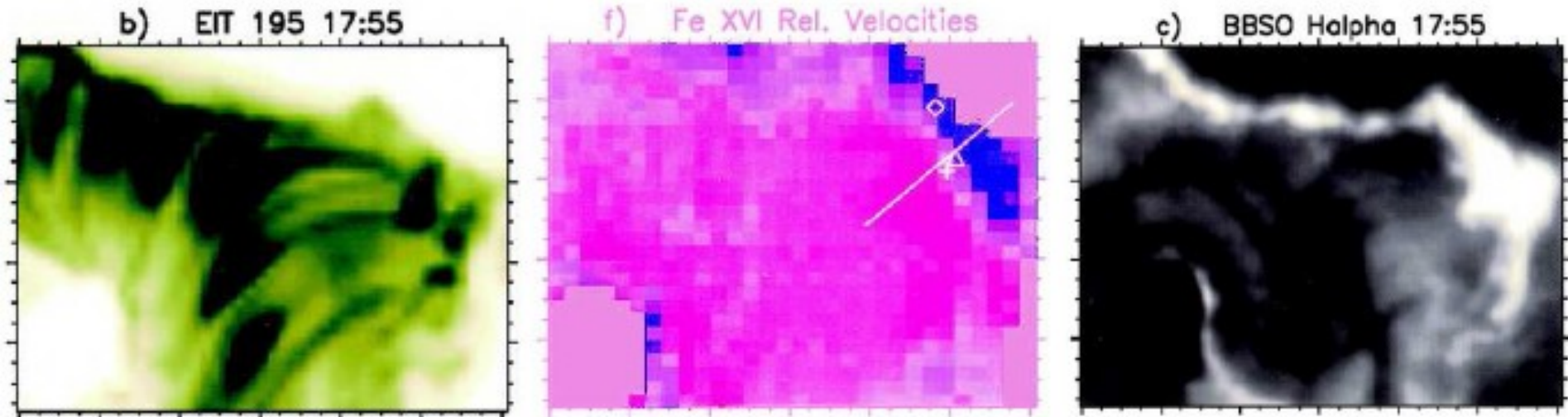
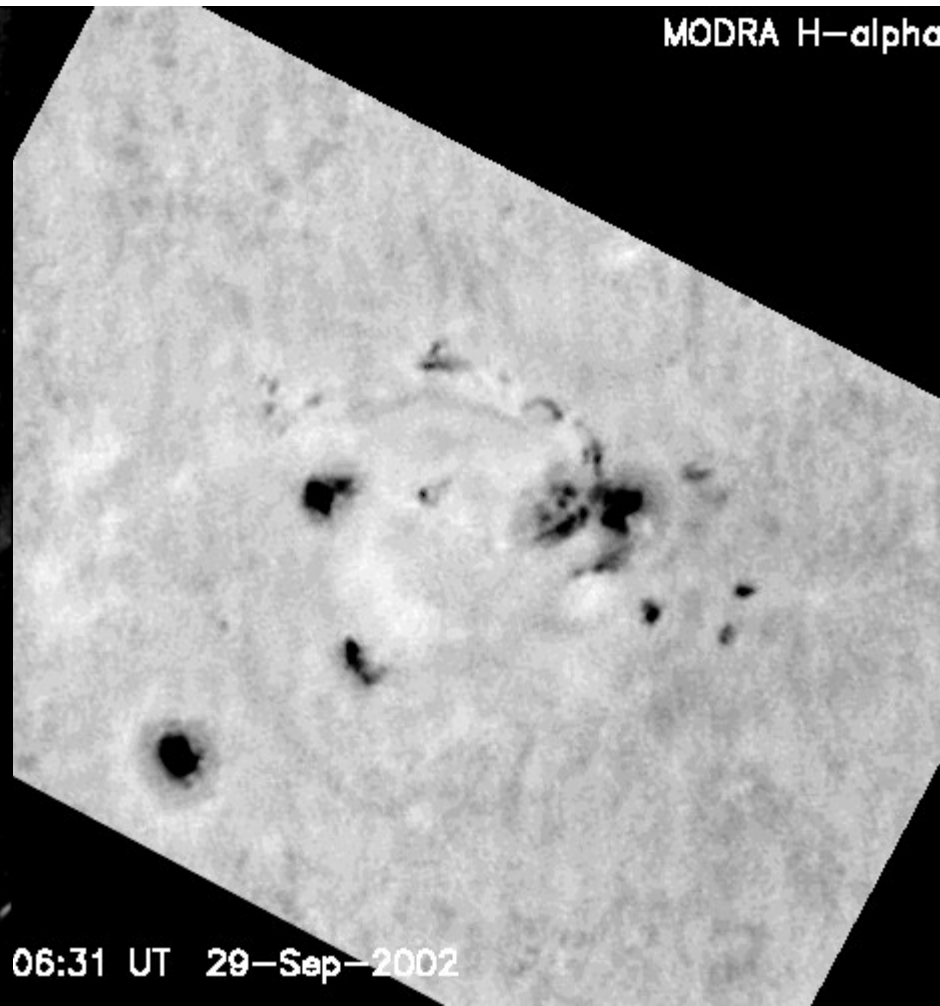
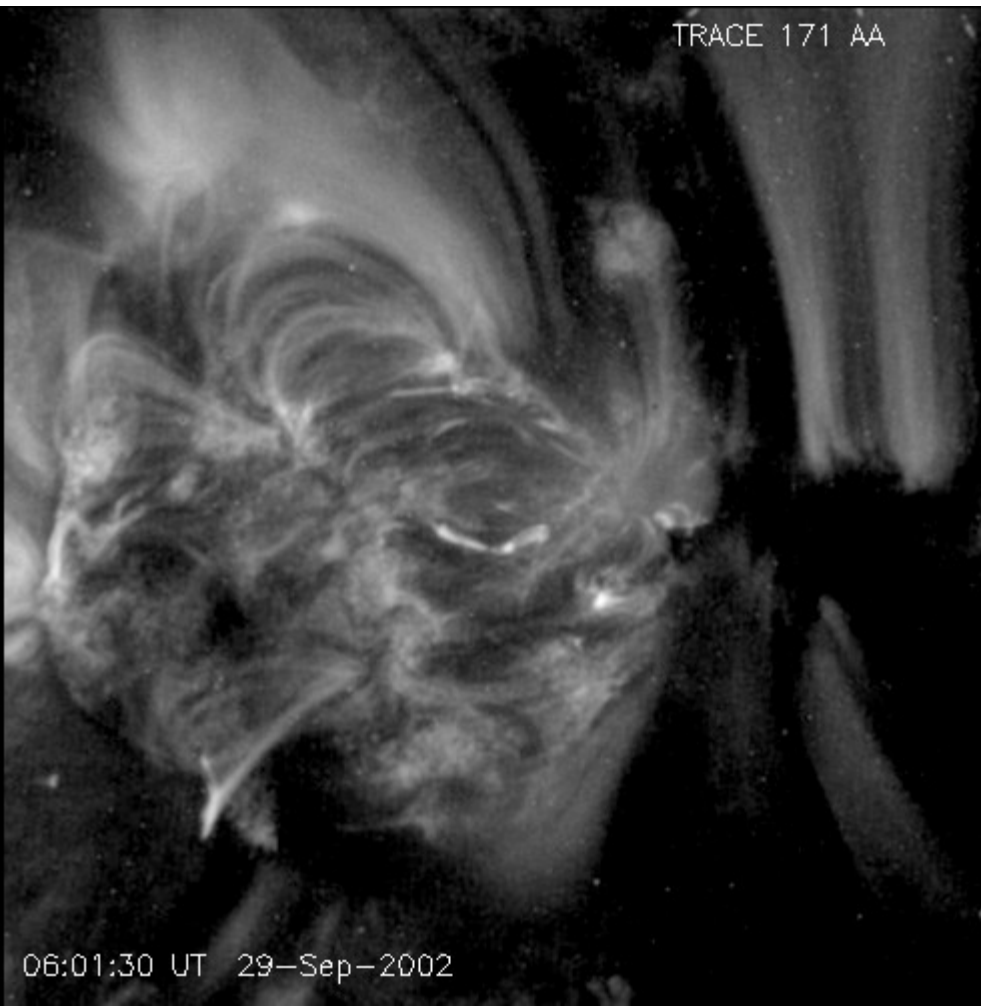


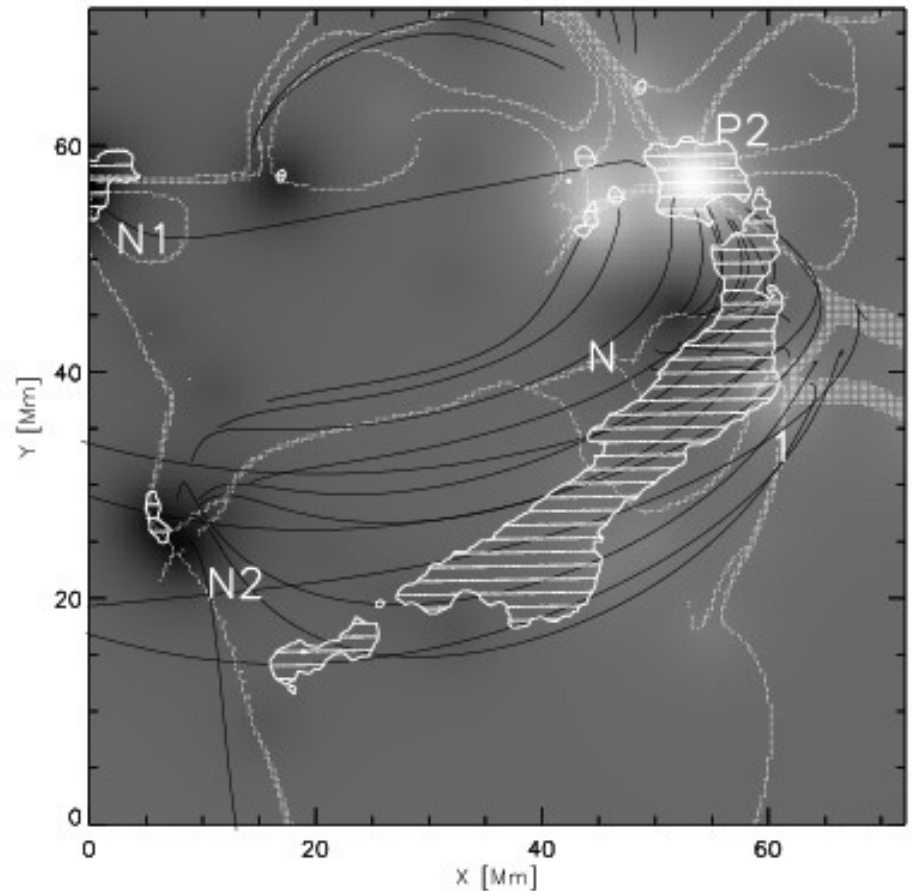
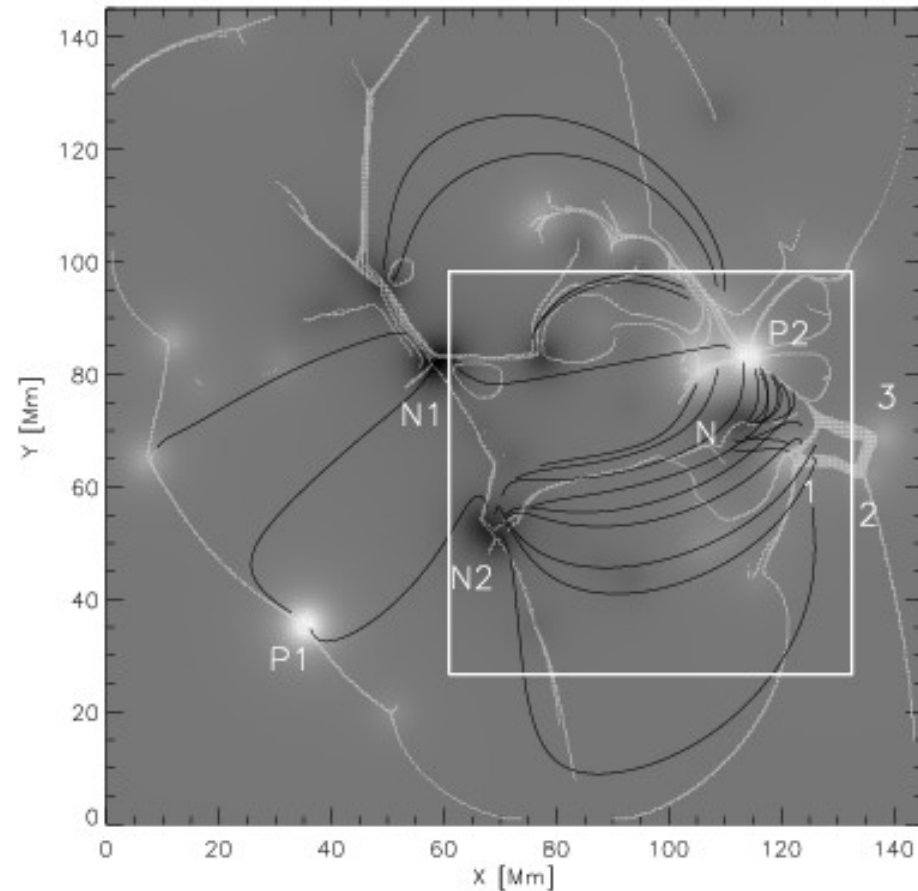
Figure 16.12: Flare of 1998-Apr-29, 16:37 UT, observed in EUV (SoHO/EIT 195 Å, left), in Doppler shift (SoHO/CDS Fe XVI; middle), and in H $\alpha$  (BBSO; right). Note that the magnetic configuration corresponds to a loop arcade, curved around the sunspot in the south-east of the image. Blueshifts are observed at the outer and inner ribbons of the curved arcade (black color in middle image), while redshifts are found in the interior of the arcade (Czaykowska et al. 1999).

# Emisia v EUV oblasti a H-alfu

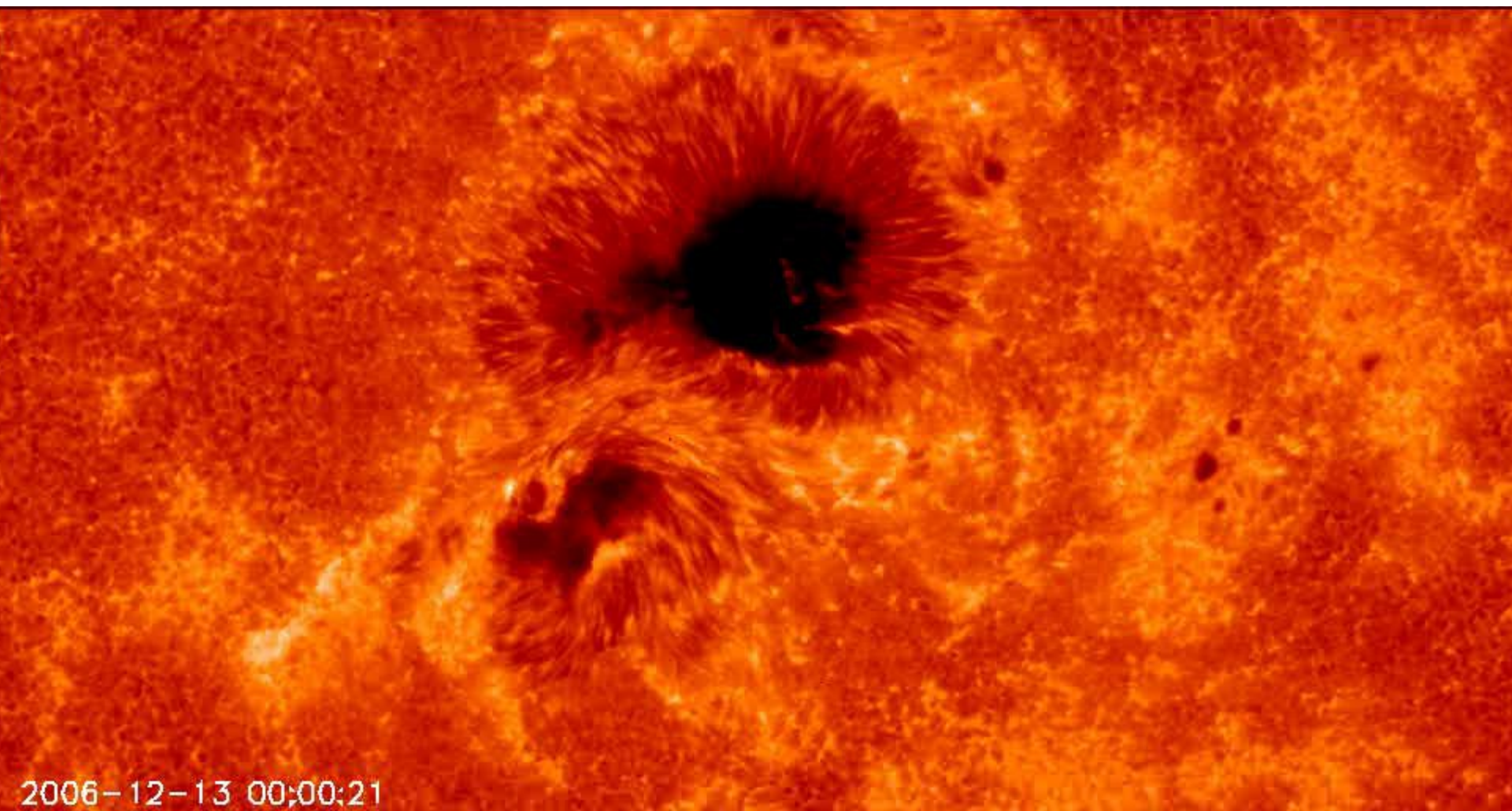


# Modelovanie magnetického poľa

Erupcia M2.6 zo 29. septembra 2002, 06:32-06:36-06:41 UT







2006-12-13 00:00:21

# H-alfa

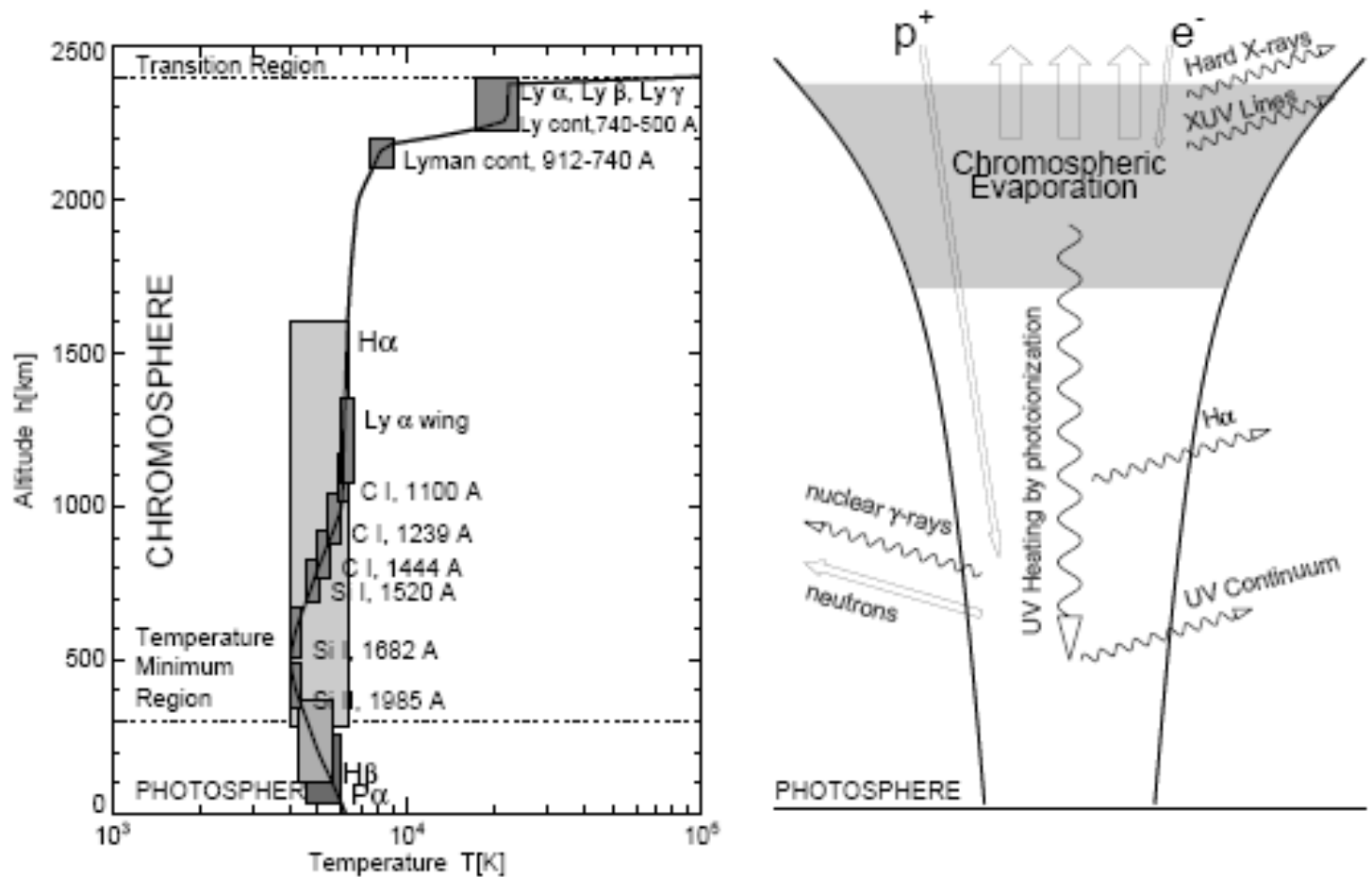
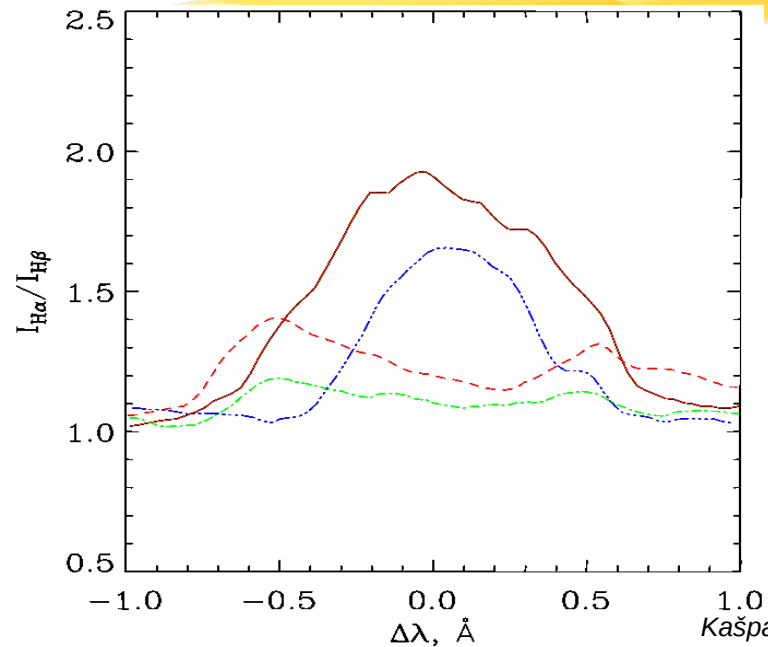


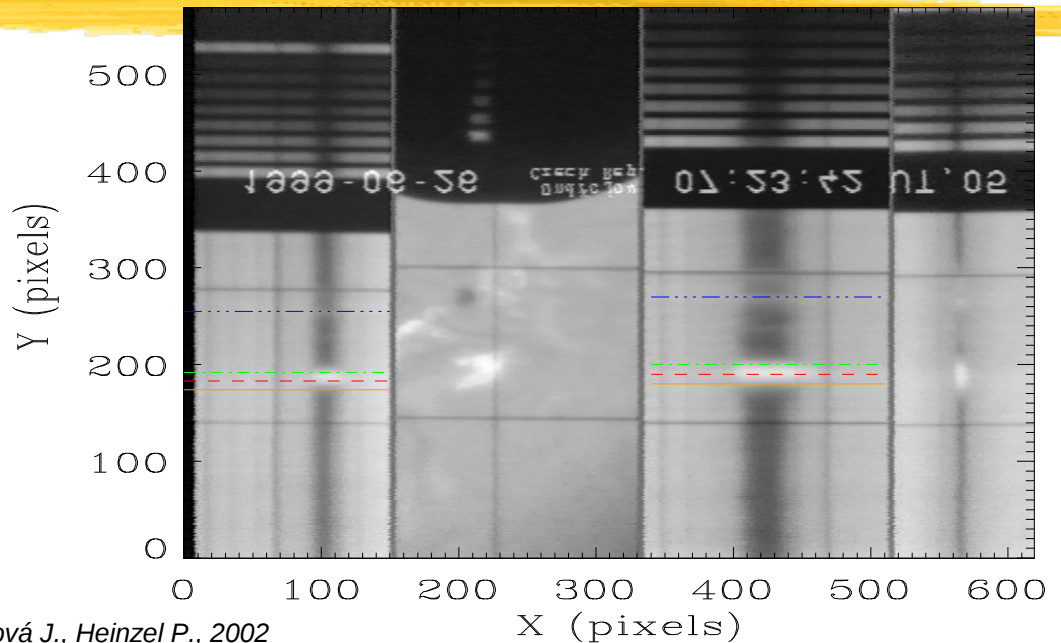
Figure 16.6: Height-temperature diagram of the origin of  $H\alpha$ , Lyman line emission ( $L\alpha$ ,  $L\beta$ ,  $L\gamma$ ), Lyman continuum, UV lines ( $T \gtrsim 20,000$  K), and UV continuum (Si I, Si II, C I) are shown (left), along with a temperature model (thick line) according to the model of Vernazza et al. (1973). The corresponding heights of the various emissions (hard X-rays, XUV lines, nuclear  $\gamma$ -rays, neutrons,  $H\alpha$ , and UV continuum) in a flare loop footpoint are sketched (right). Chromospheric evaporation is caused by heating of precipitating electrons, nuclear  $\gamma$ -rays by precipitating protons, and UV continuum emission by photo-ionization from collisional bremsstrahlung in the upper chromosphere, also called *backwarming* (adapted from Vernazza et al. 1973; Brown & Smith 1980; Dennis 1988).



# Modelovanie čiary H-alfa

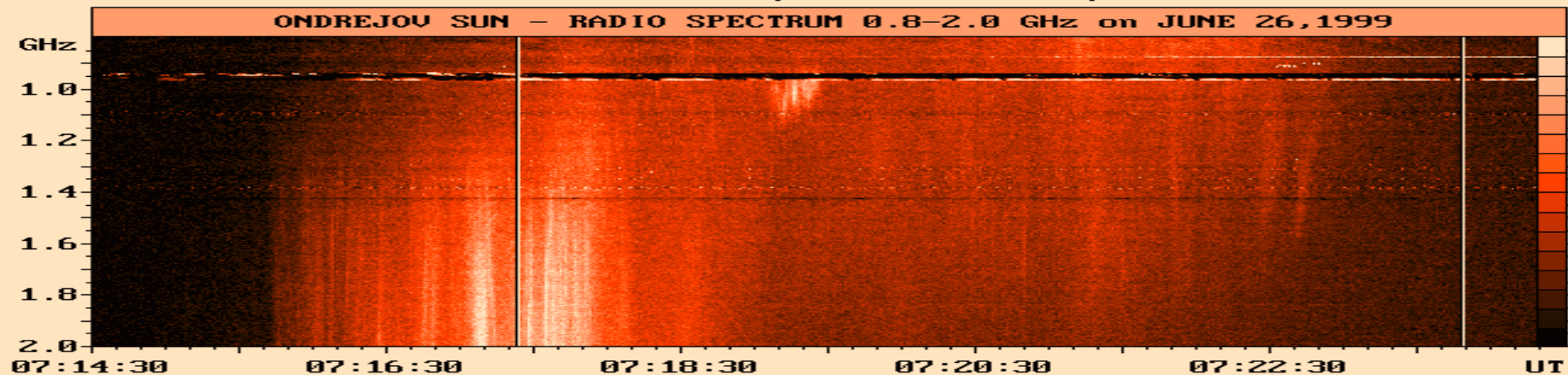


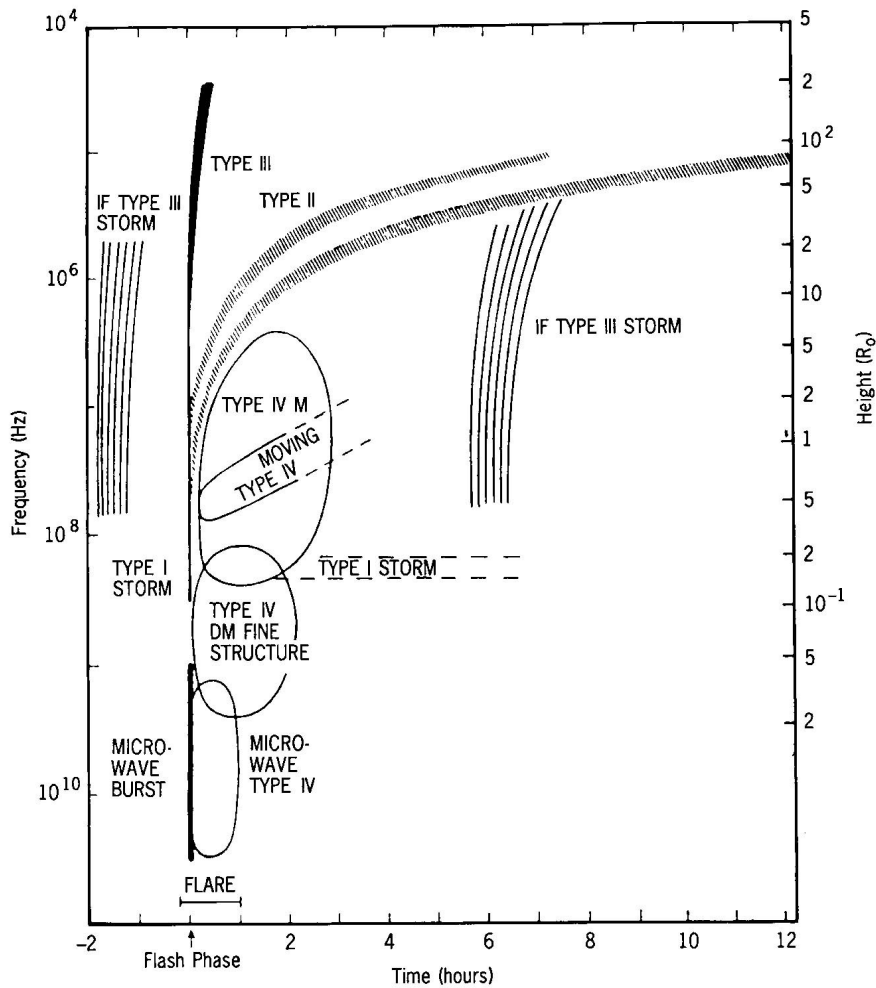
Kašparová J., Heinzel P., 2002



(c) ASTRONOMICAL INSTITUTE, 25165 ONDREJOU, CZECH REPUBLIC

ONDREJOU SUN - RADIO SPECTRUM 0.8-2.0 GHz on JUNE 26, 1999





**Fig. 10-16** The radio spectrum of a large flare. The low-frequency Type III and Type I storms preceding and following the flare are not necessarily part of the flare. Only one Type III burst has been drawn, although a group of about ten occurs at the flash phase. Only the envelopes of the Type IV burst have been drawn; usually only parts of them are filled. The height scale on the right-hand side corresponds to the plasma level of the frequency scale on the left-hand side. Adapted from H. Rosenberg, *Phil. Trans. Roy. Soc. London A*, **281**, 461 (1976).

Typ **Nekoherentná rádiová emisia**  
*voľno-voľná tepelná emisia,  $\nu \approx 1$  GHz*

I *plazmová emisia*

*gyroemisia,  $\omega \approx s\Omega$*

*$s=1-4$  tepelné elektróny,*

*$s=10-100$  relativistické elektróny*

I *tepelné a relat. elektróny*

IV moving *zachytené elektróny*

IV mikrovlnné *zachytené elektróny*

Typ **Koherentná rádiová emisia**

*plazmová emisia*

*elektrónové zväzky,  $\nu = 9000 \sqrt{h}$*

I *šumová emisia, dlhožijúca (až dni),  
 takmer 100% polarizácia  $\Rightarrow$  oscilácie  
 plazmy excitované energetickými  
 elektrónmi.*

II *spôsobená pohybom poruchy smerom  
 nahor, 2 diskkrétne frekvencie, základná  
 a druhá harmonická*

III *nahor (nadol) sa pohybujúce zväzky*

IV *gyrosynchrotrónna emisia elektrónov  
 zachytených v plazmovom oblaku  
 (rádiový prejav CME)*

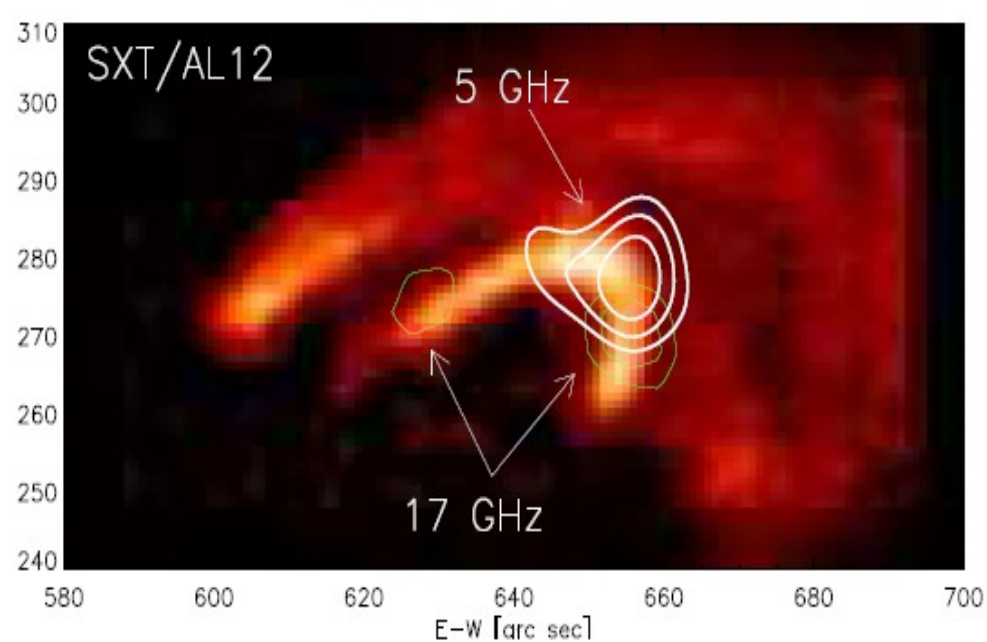


Figure 15.8: Microwave data during the 1993-Jun-3 flare, showing the radio intensity peaks (contours) on top of a soft X-ray image from a filtered *Yohkoh* SXT/Al12 at 23:39 UT. Contours are 80% to 99% of the maximum intensities:  $1.8 \times 10^7$  K at 5 GHz and  $1.2 \times 10^5$  K at 17 GHz respectively. The 5 GHz (looptop) source is produced by gyrosynchrotron emission, while the 17 GHz (footpoint) sources could be a combination of gyrosynchrotron and free-free emission (Lee & Gary 2000).

## RTG - RÁDIO

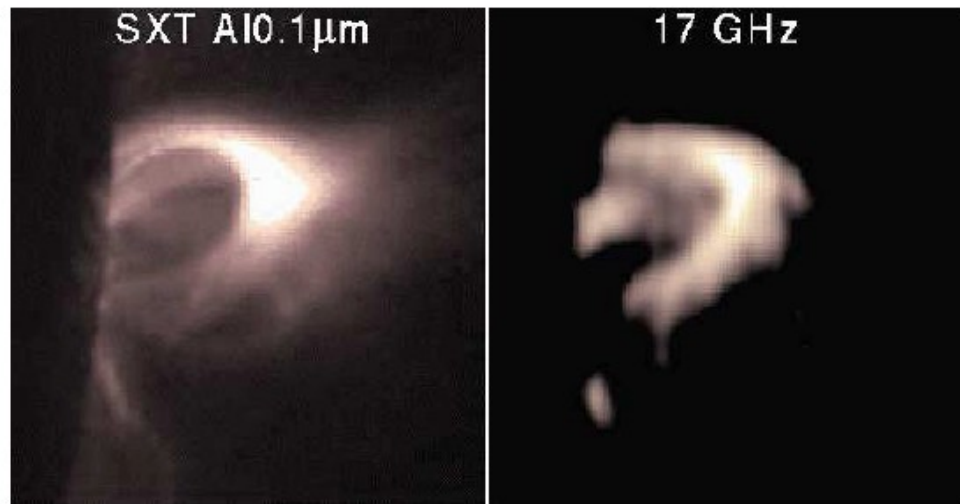
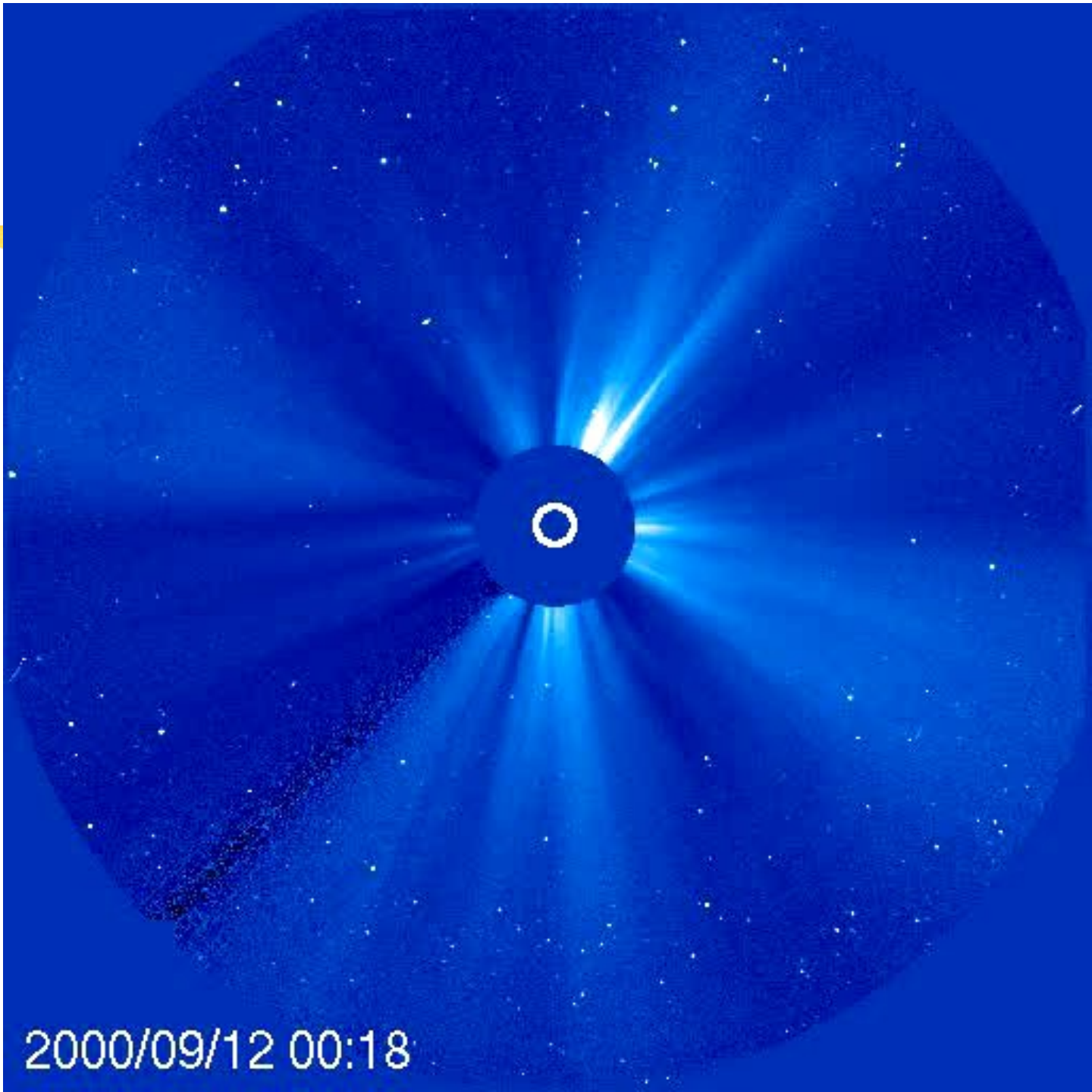


Figure 15.3: Observations of the long-duration flare event of 1993-Mar-16 with the *Nobeyama Radioheliograph* at 17 GHz and *Yohkoh/SXT*. Note the common loop-like structure, although there are little differences due to the different instrumental temperature responses (Hanaoka 1994).

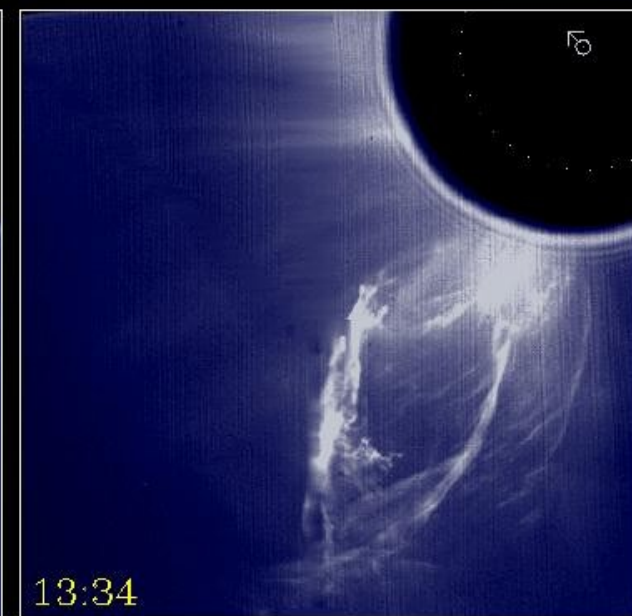
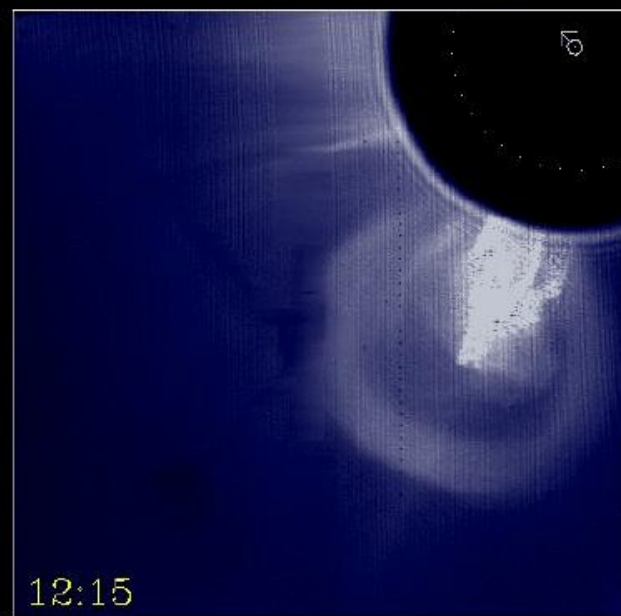
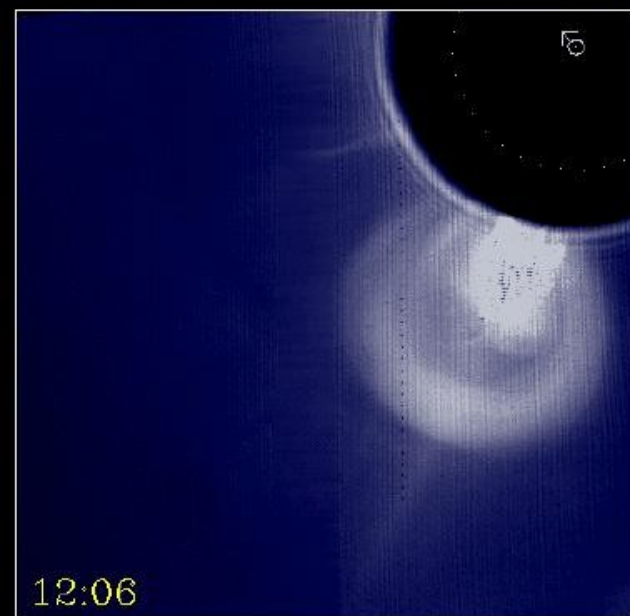
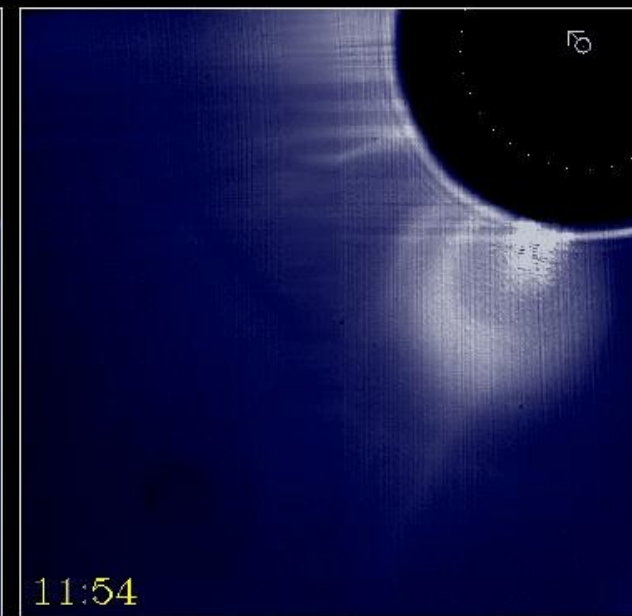
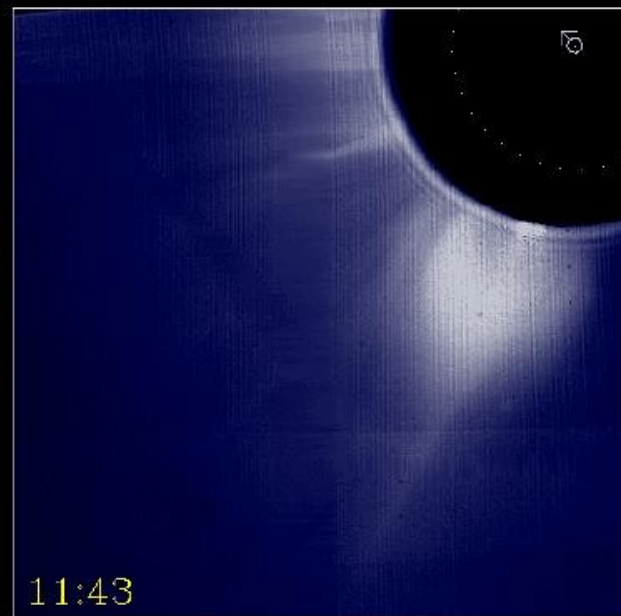
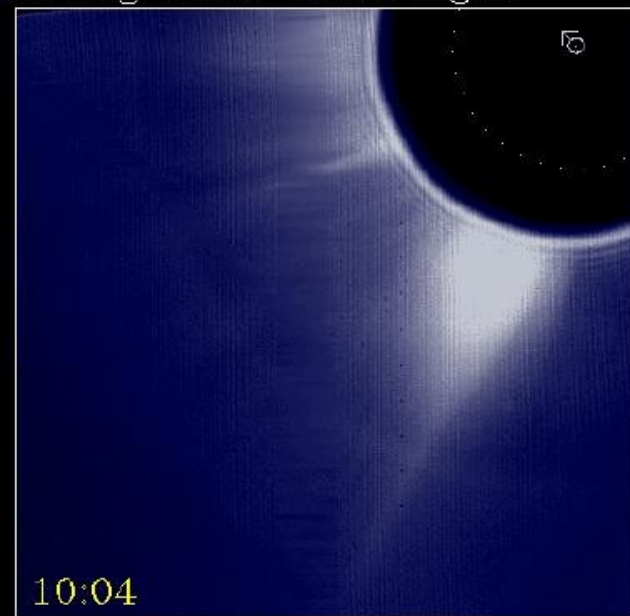


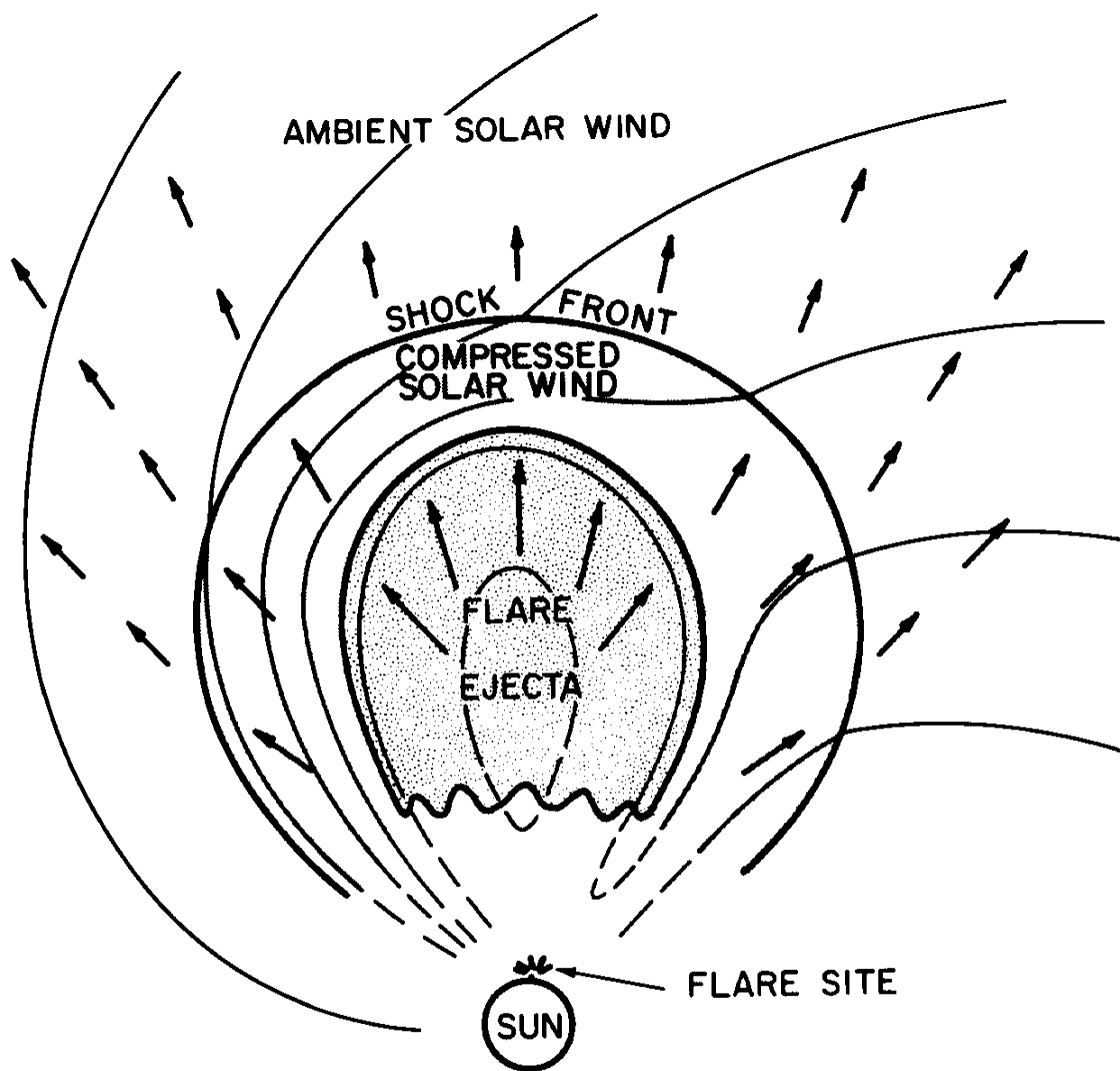
**CME**



2000/09/12 00:18

18 Aug 1980: White Light





**Fig. 12-10** A qualitative sketch, in equatorial cross-section, of a flare-produced shock wave propagating into an ambient solar wind. The arrows indicate the plasma flow velocity and the light lines indicate the magnetic field. Reproduced by permission, from A. Hundhausen, *Coronal Expansion and Solar Wind*, Springer-Verlag, N.Y., 1972.



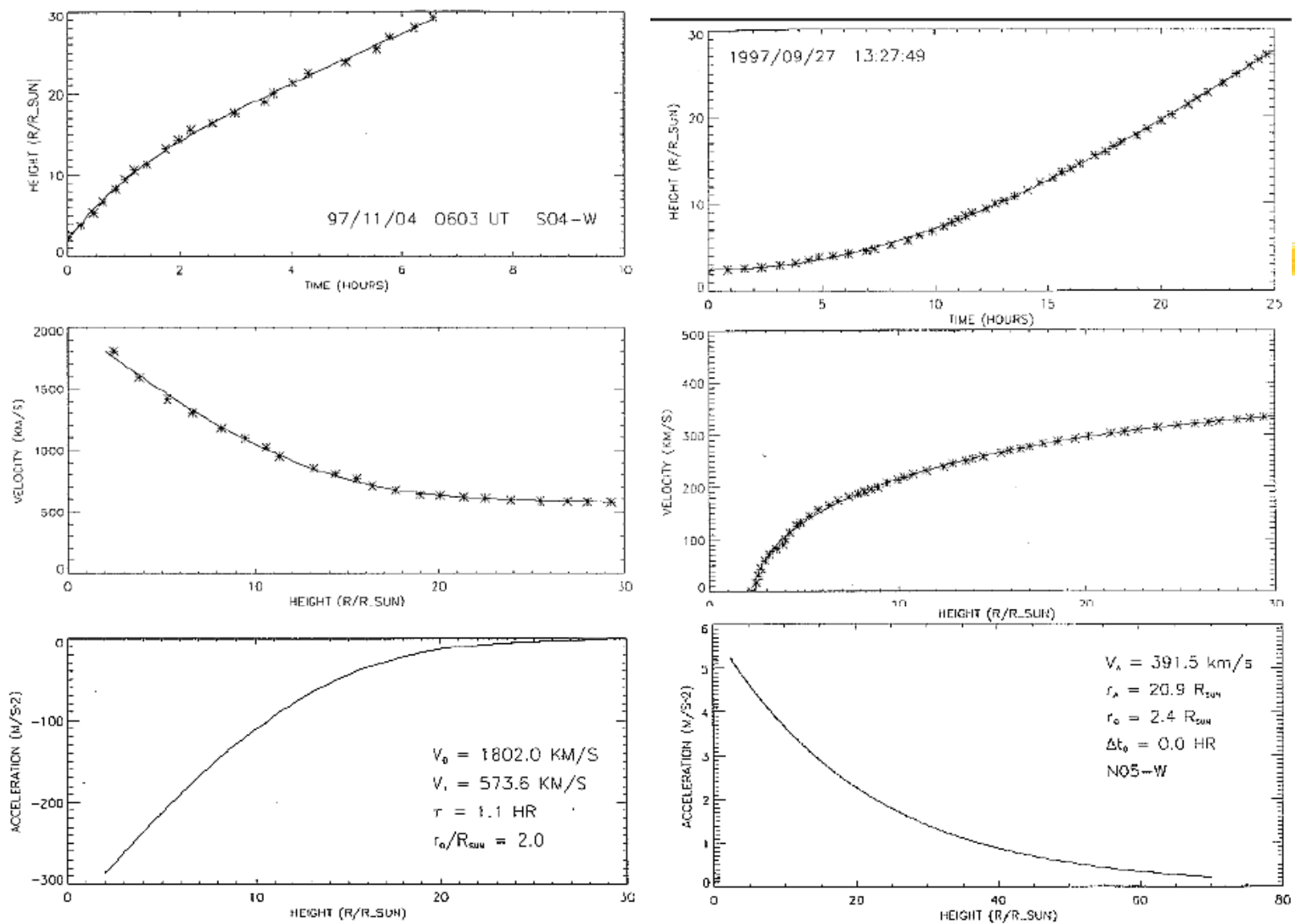
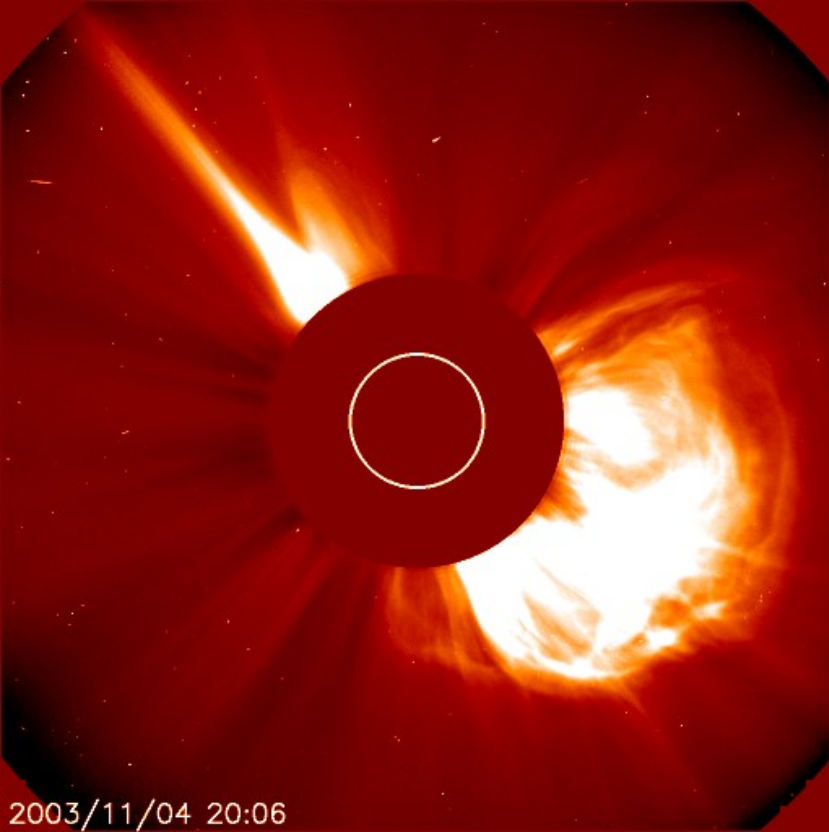
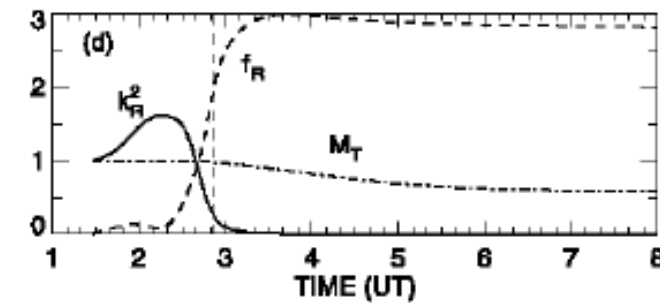
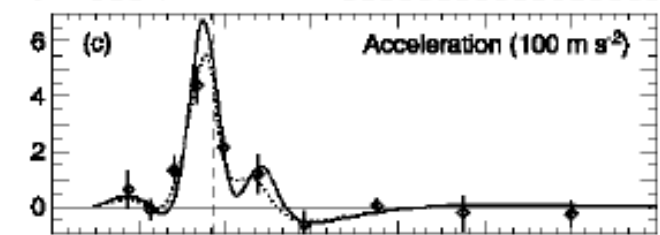
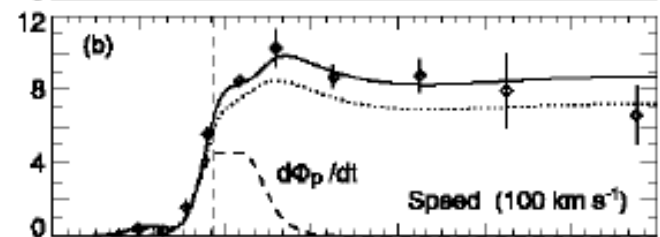
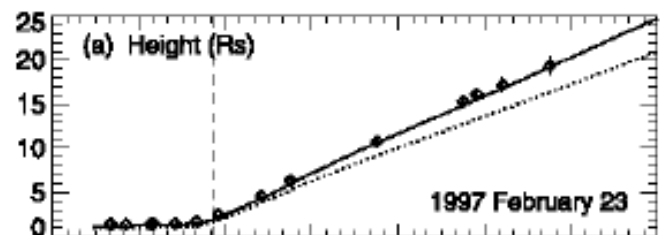
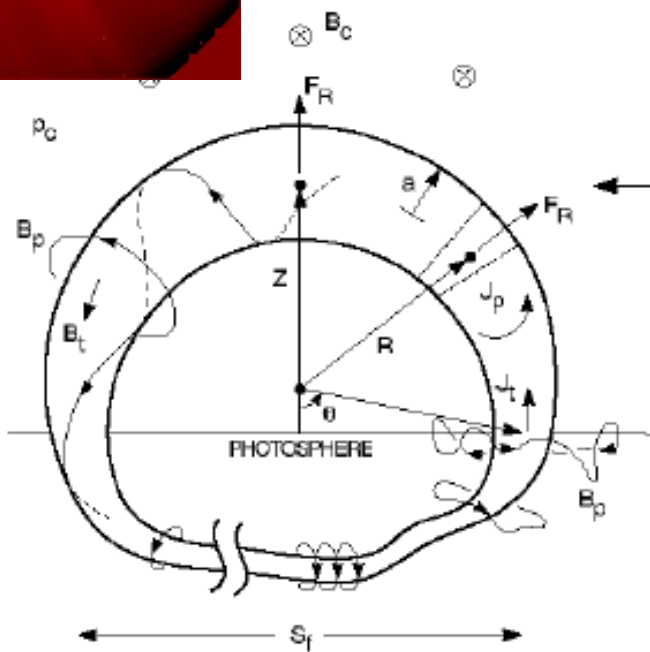


Figure 17.11: Height-time  $h(t)$  plot (top), velocity  $v(r)$  (middle), and acceleration profiles  $a(r)$  (bottom), as a function of distance  $r/R_{\odot}$ , are shown for representants of two different CME classes: a gradual CME with initially negative acceleration (right), and an impulsive CME with initially positive acceleration (left) (Sheeley et al. 1999).



2003/11/04 20:06



relative density  $(\rho - \rho_{wind})/\rho_{wind}$

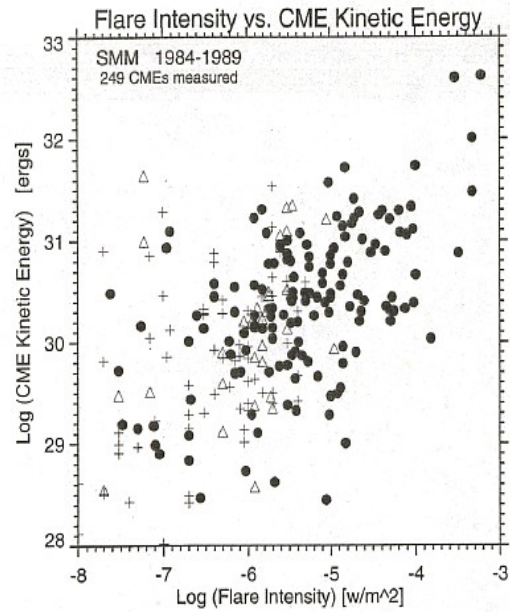
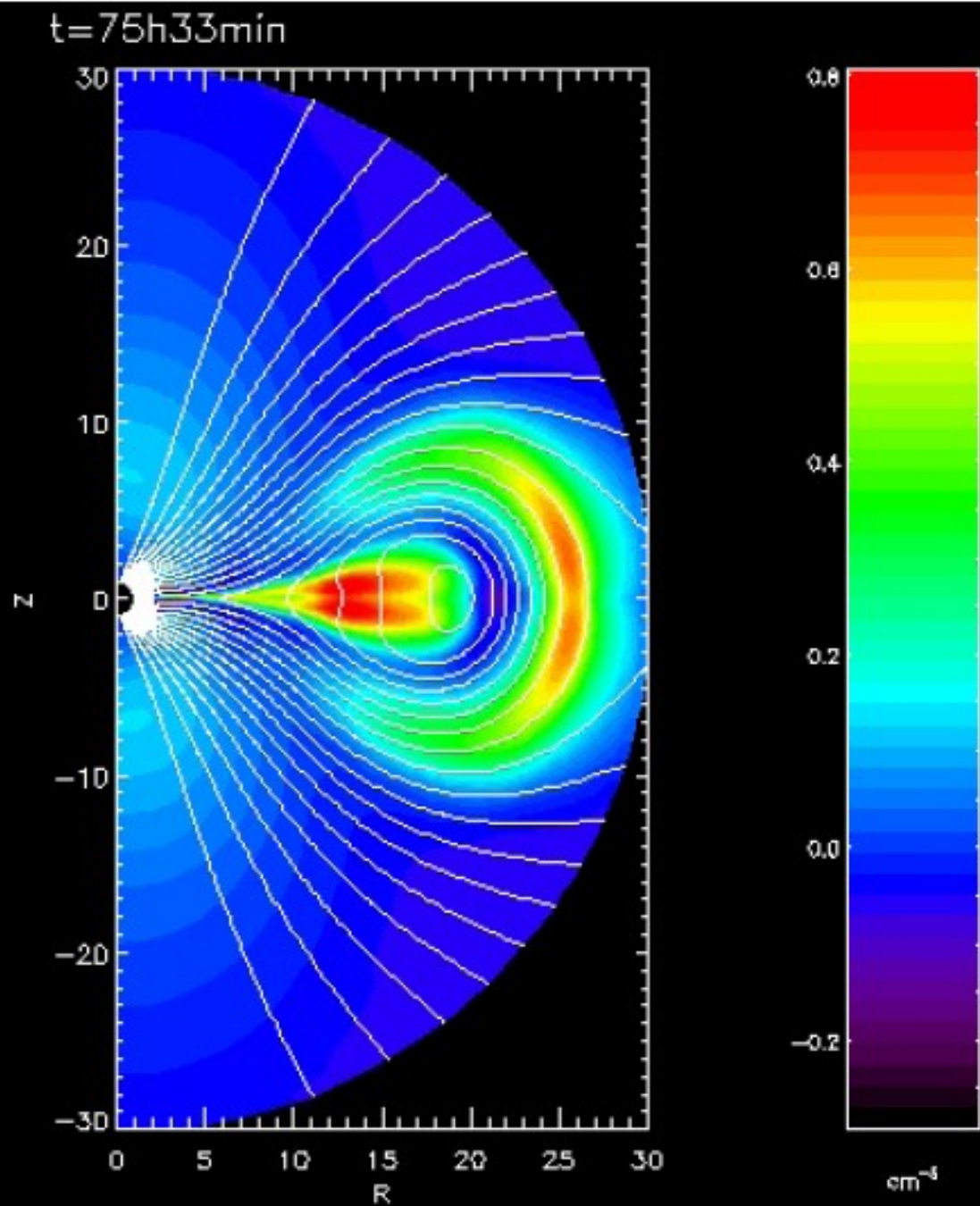


Figure 17.15: A logarithmic scatterplot of kinetic energies of CMEs and the peak intensities of associated X-ray flares seen in the GOES integrated soft X-ray flux. The sample includes 249 CME events observed with SMM C/P (Hundhausen 1997).



# CME - ZEM





**Ďakujem za pozornosť**





