Streamers: A transition from Corona to Jet.

VLBI Discovery of Coronal Streamers in a Stellar System

Maria Massi

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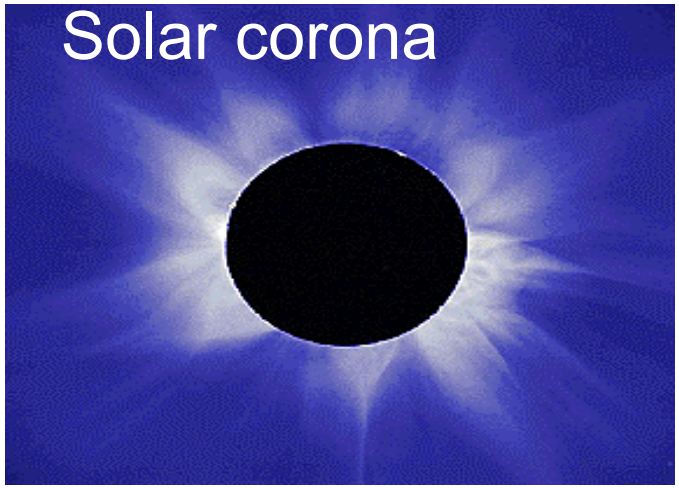
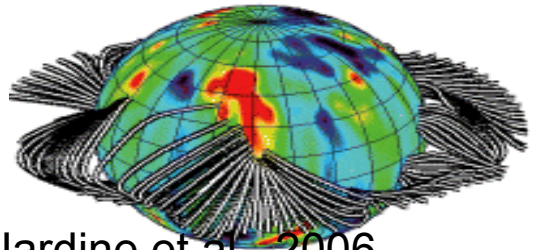
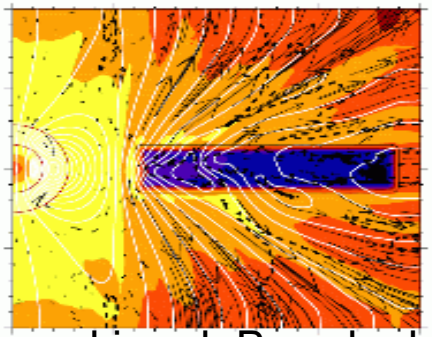




Jardine et al. 2006



von Rekowski and Brandenburg 2004

Coronae

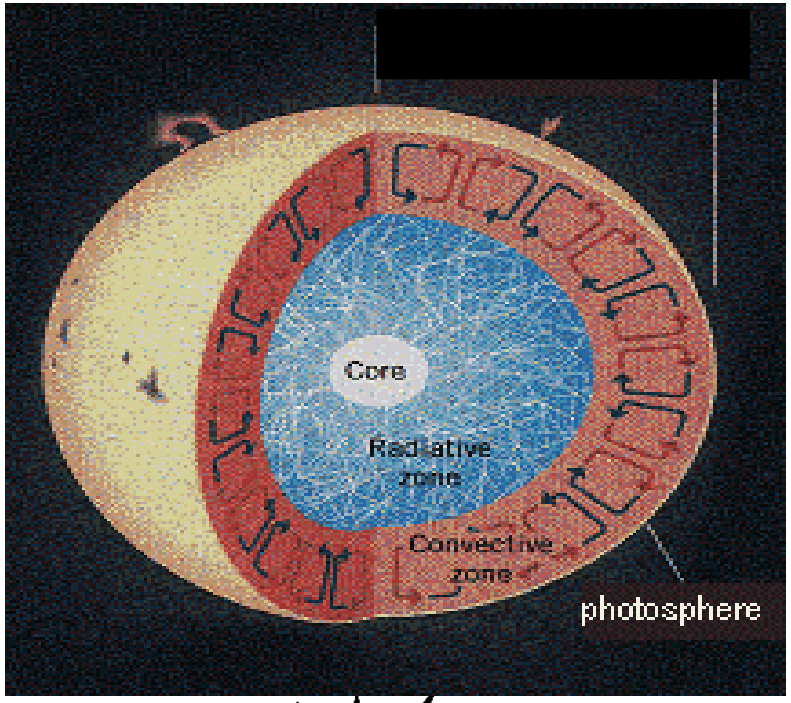
are a general phenomenon present among a wide variety of objects.

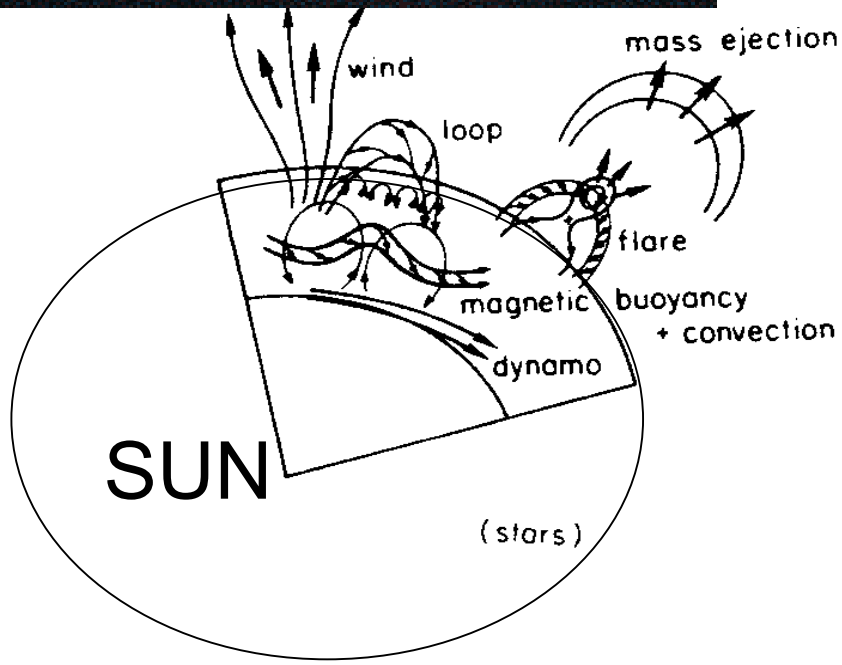
- Sun / cool stars

- Young stellar objects generally show highly elevated levels of coronal activity.

- Accretion disks, which exist around protostars, degenerate stellar objects,and supermassive black holes, can be surrounded by a corona.

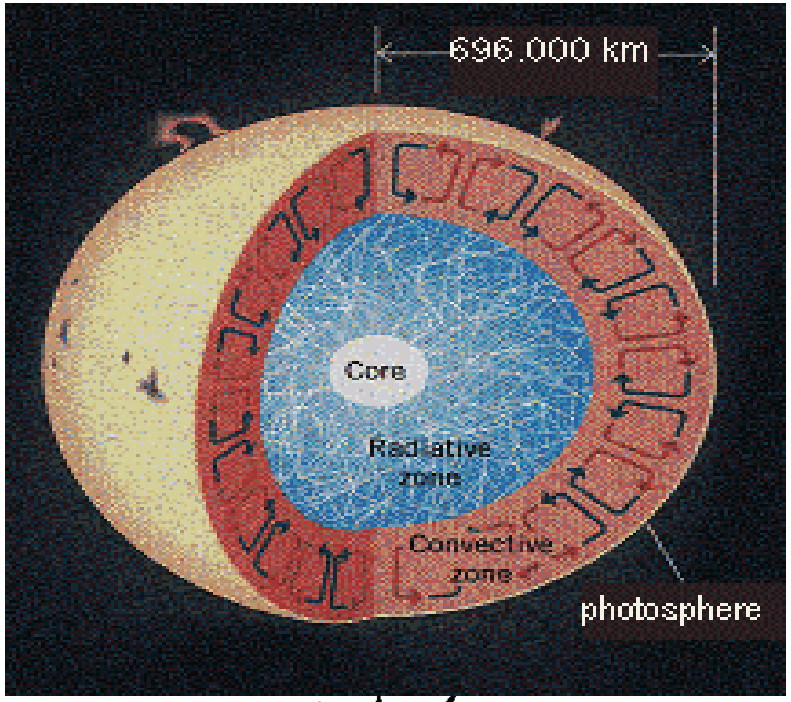
The solar corona has been observed / studied in greatest detail. How different are the other coronae ?

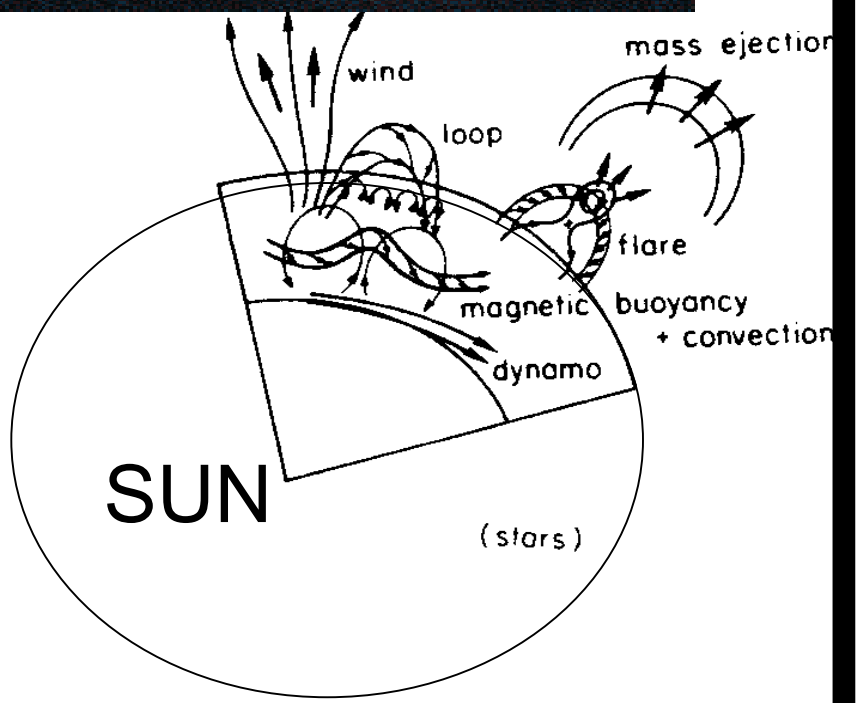


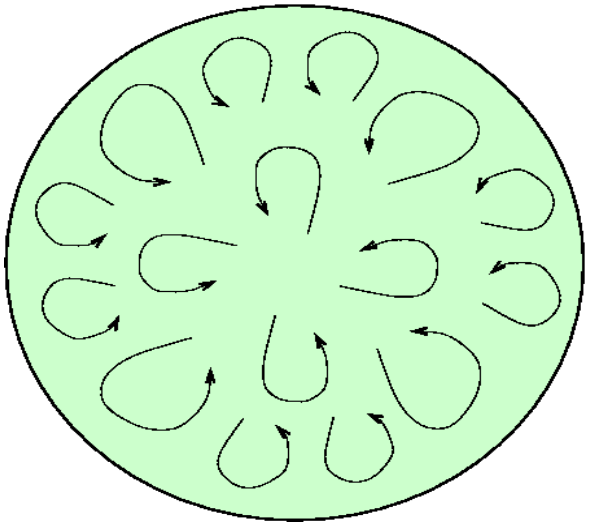


In the solar dynamo, i.e. the physical process that generates the Sun's magnetic field,
a toroidal field is created at the tachocline.....

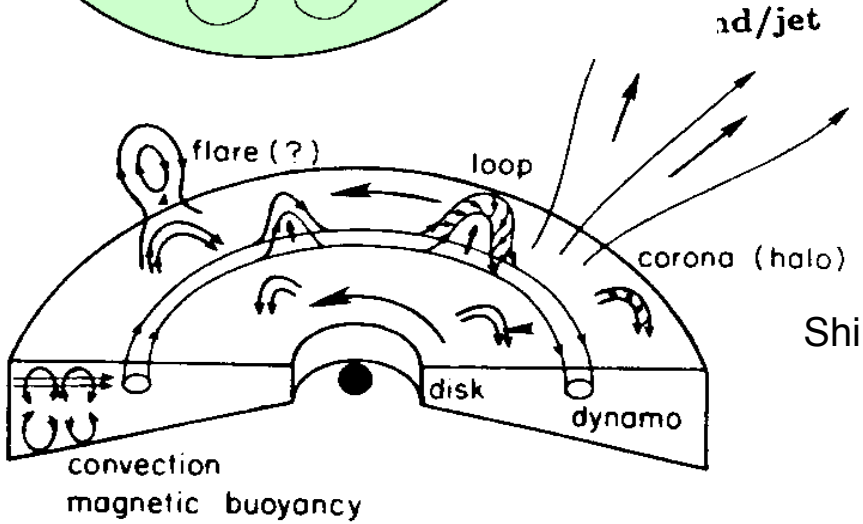
In a second stage, tubes of toroidal flux emerge to the surface (because of magnetic buoyancy) creating the coronal loops (i.e. the building blocks of the corona)







the tachocline is missing in fully convective objects



Shibata

(disks)

In order to investigate

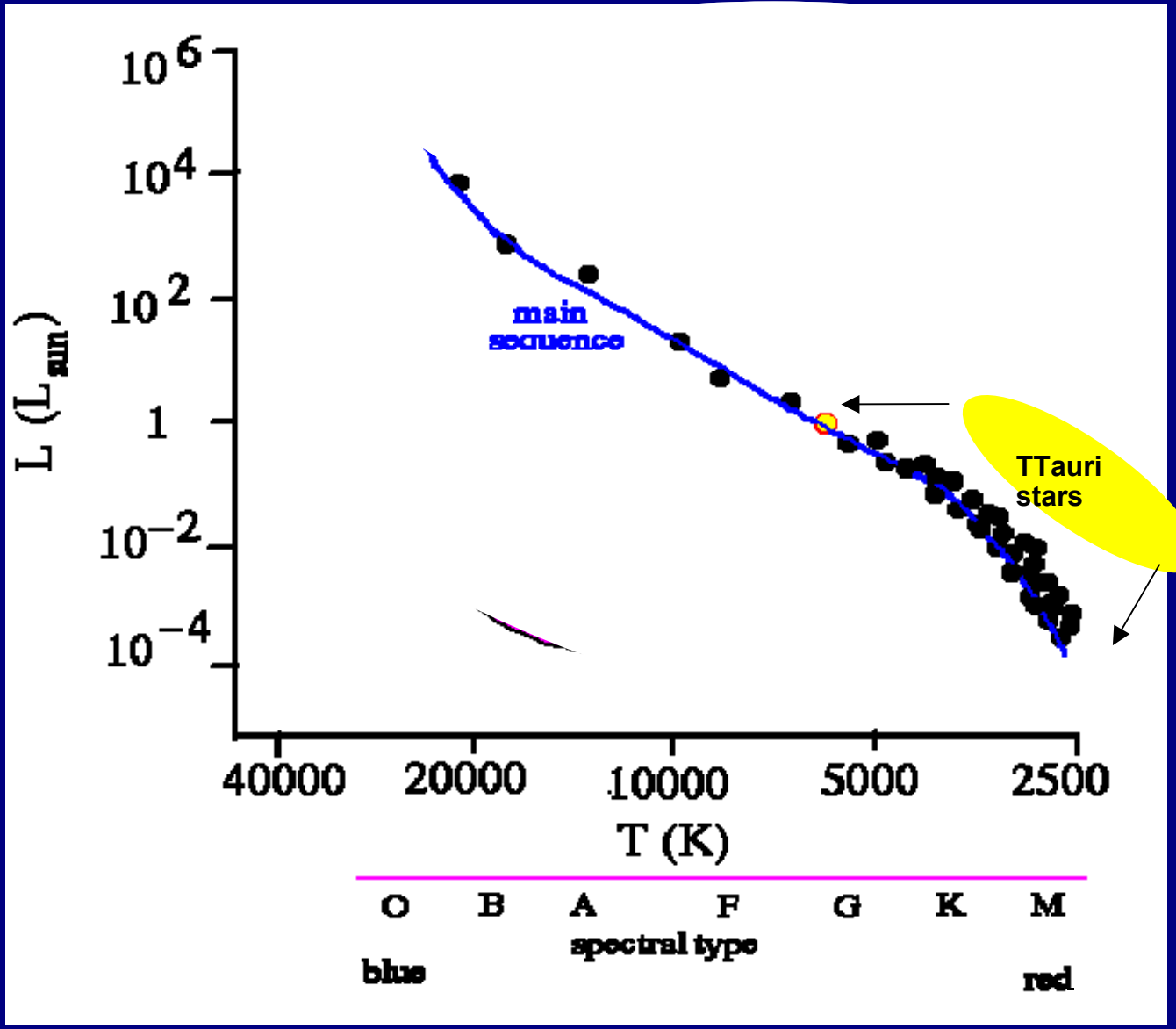
the structure of the corona in
fully / nearly fully convective objects

we performed a series of observations on
weak-line T Tauri stars

Weak-line T Tauri Stars

are pre-main sequence objects,

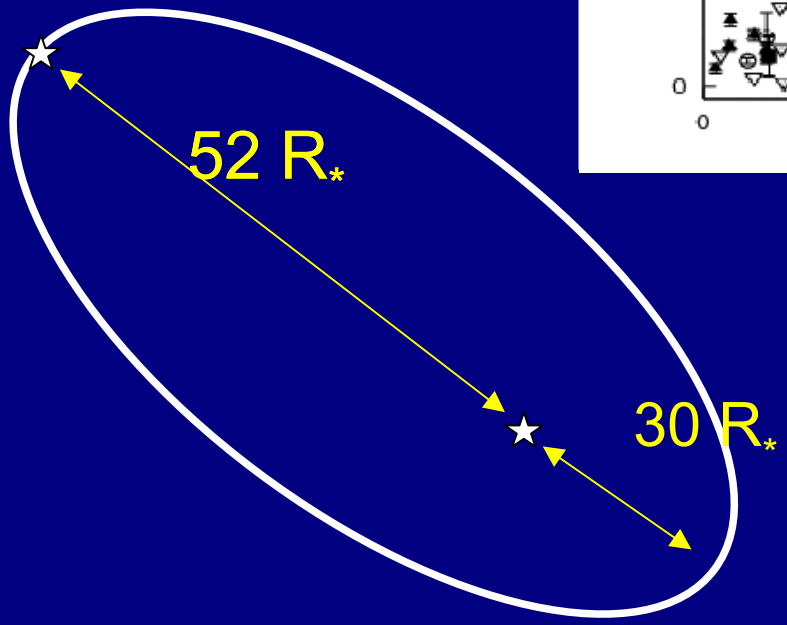
where the radiative zone either is still missing or is deeply embedded and therefore corresponds to a very different situation with respect to the thin convective shell of the Sun.

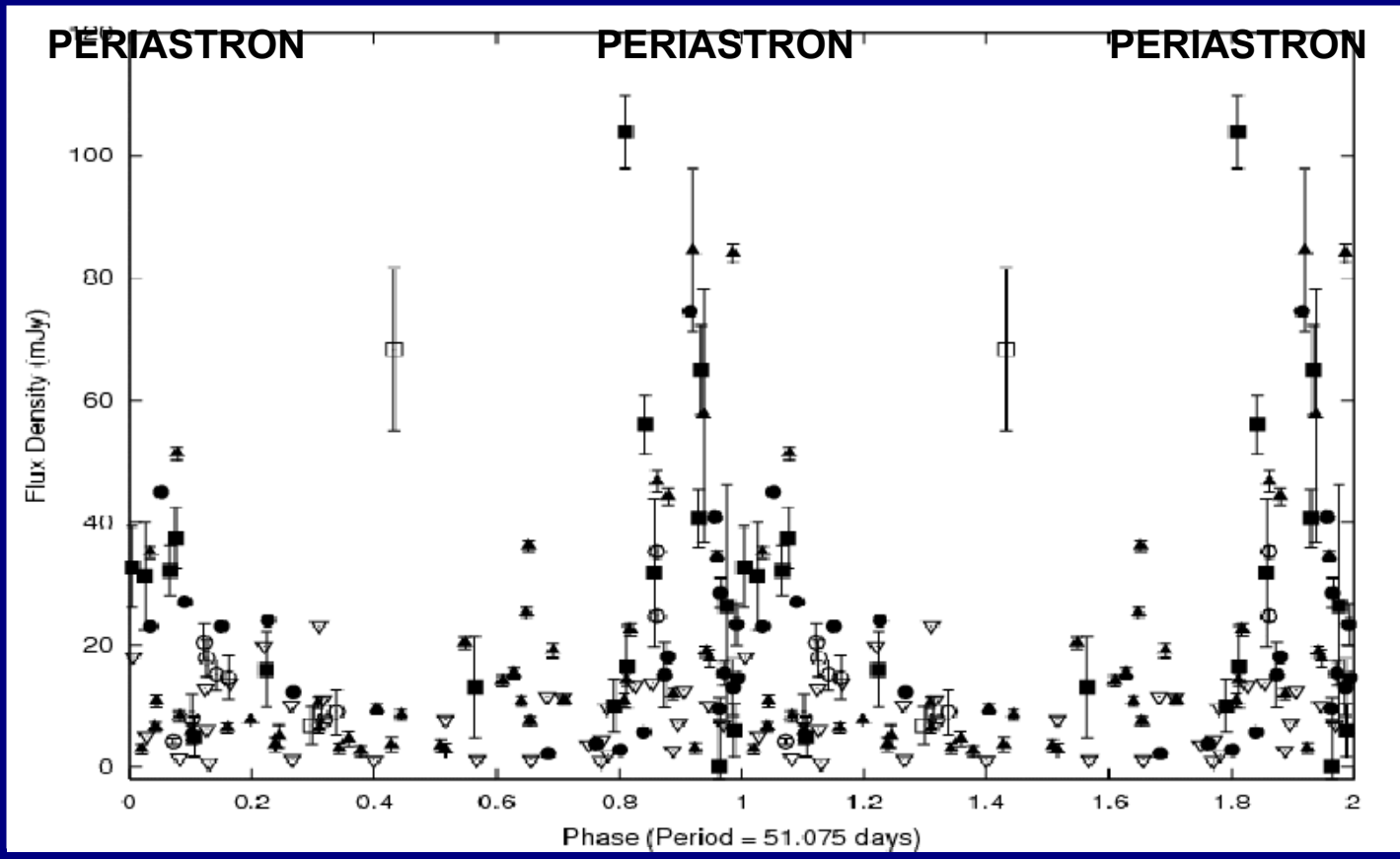


V773 Tau A

a binary system

Effelsberg 100-m telescope and VLA





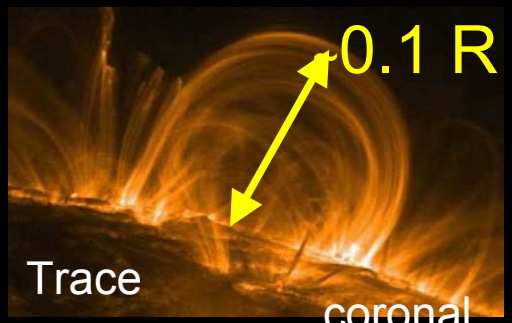
Massi, Menten, Neidhöfer 2002

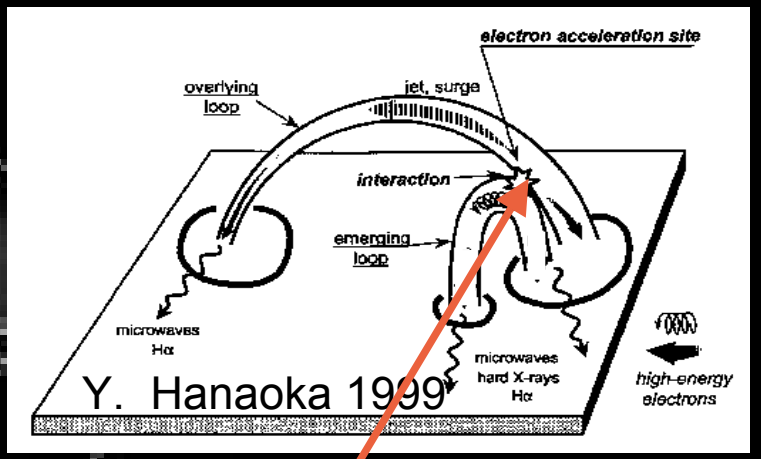
Periastron passage: Large flares

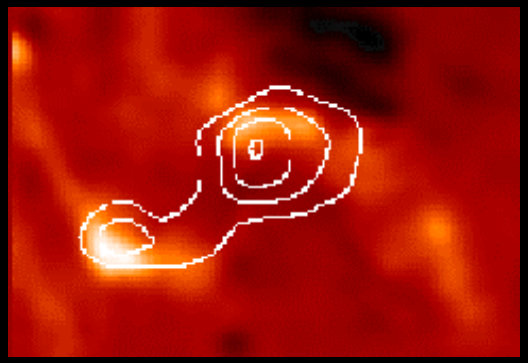
Clustering of energetic flares around the periastron passage

X-rays

SUN:

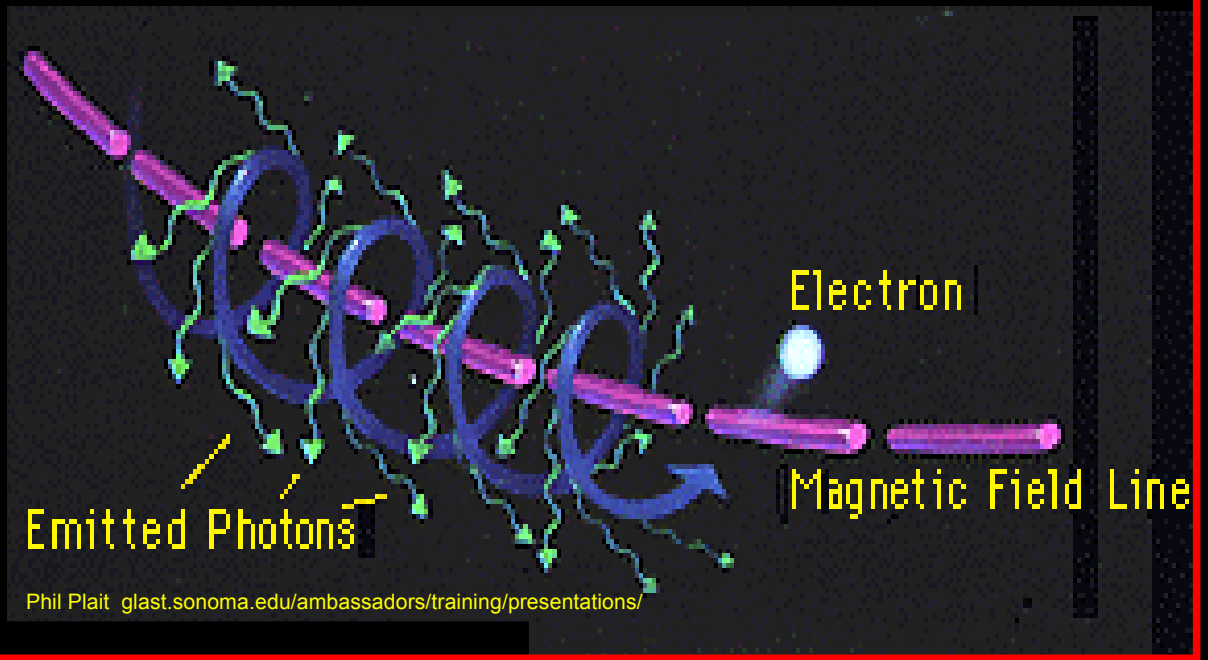




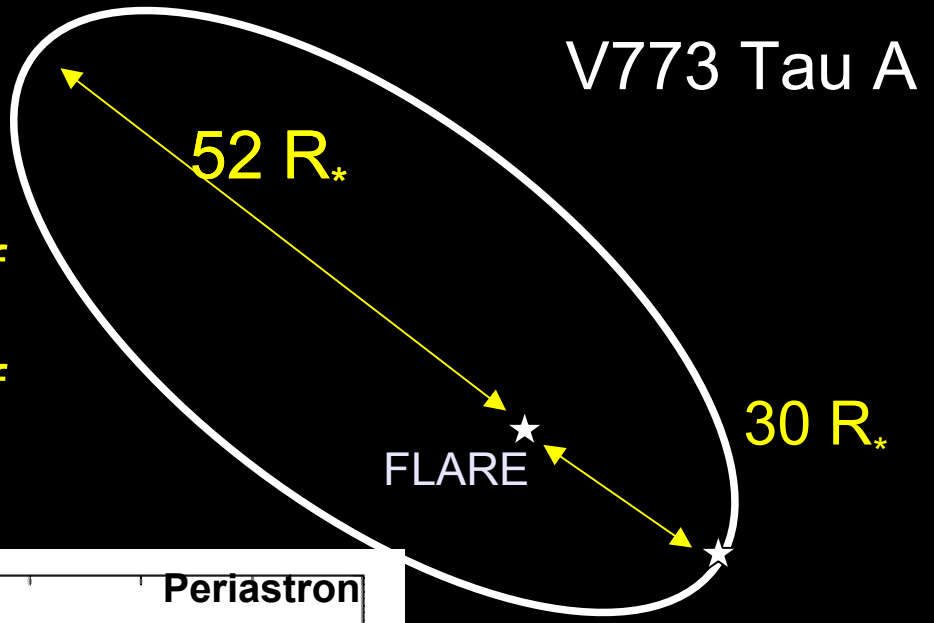


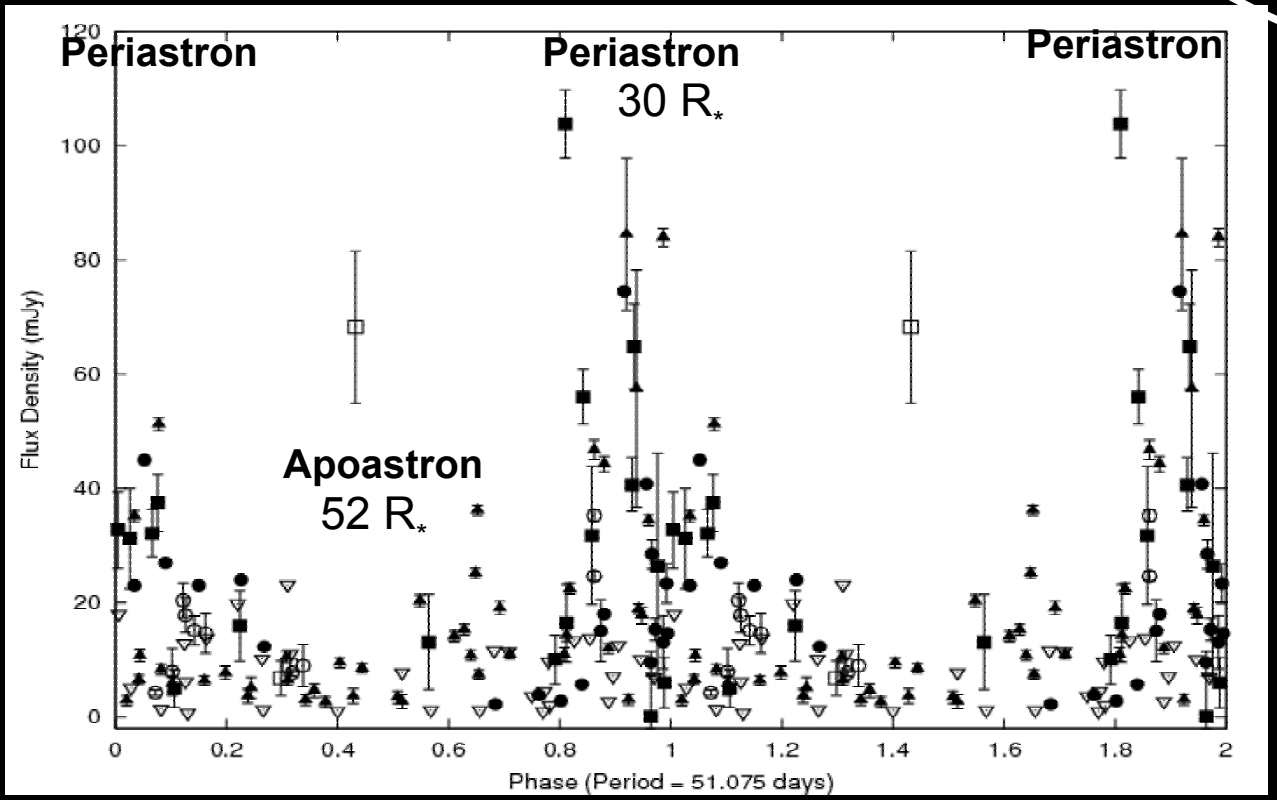
/www.aoc.nrao.edu/intro/solar.flare.gif

Radio wavelengths



In V773 Tau A the relationship between intensity of the flare occurrence and distance of the two stars indicates another new mechanism of magnetic interaction:
The interaction of coronae.





Magnetic reconnection is taking place far out from the stellar surfaces, where the two coronae interact one with each other.

15 R < H < 26 R

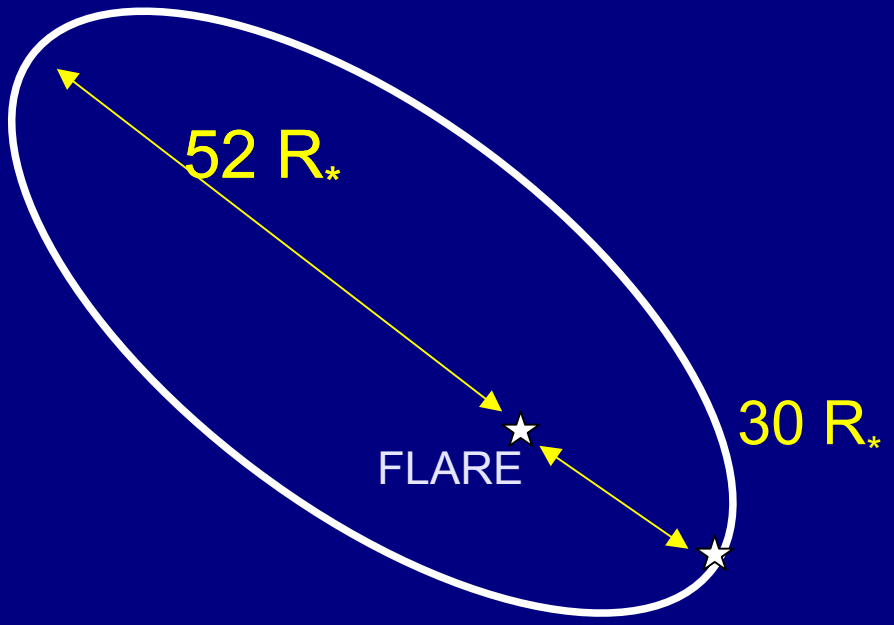
X-ray observations Radio Observations

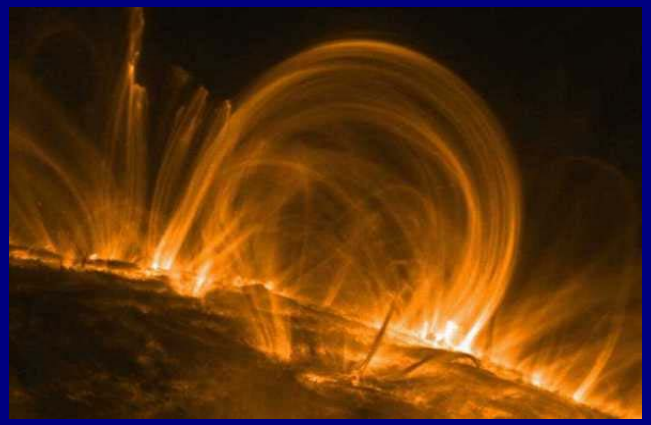
V773 Tau A

Skinner et al. (1997)
Tsuboi et al. (1998)

Size of ~1 stellar radius

Size of > 15 stellar radii

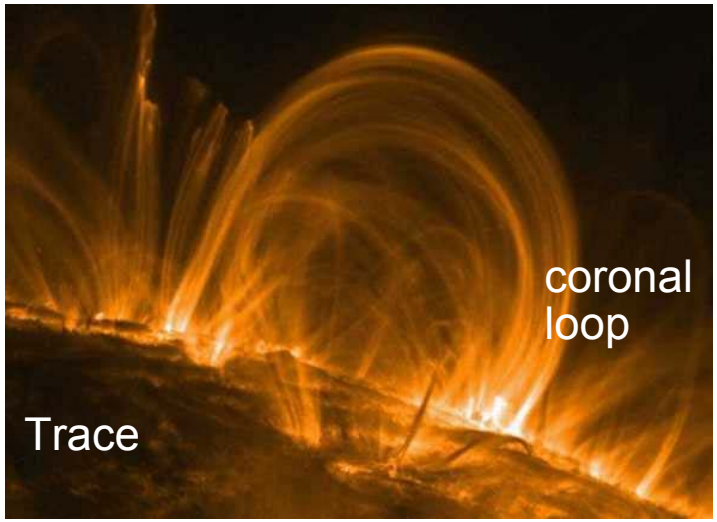




Feigelson et al. (1994) observed a steady X-ray flux combined with radio variability

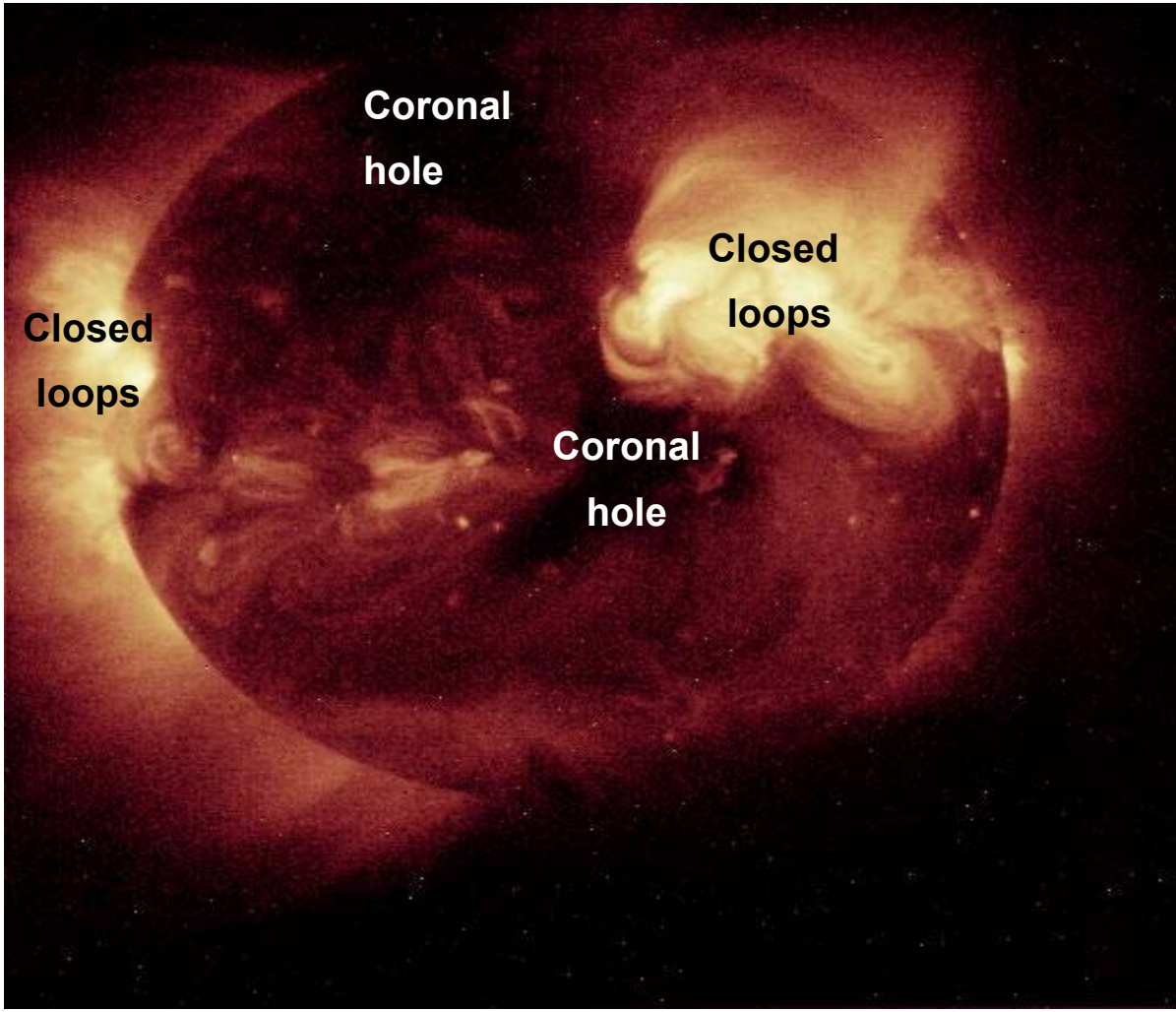
Radio and X-ray emission come from spatially separated regions

The Solar Corona Observed in X-rays

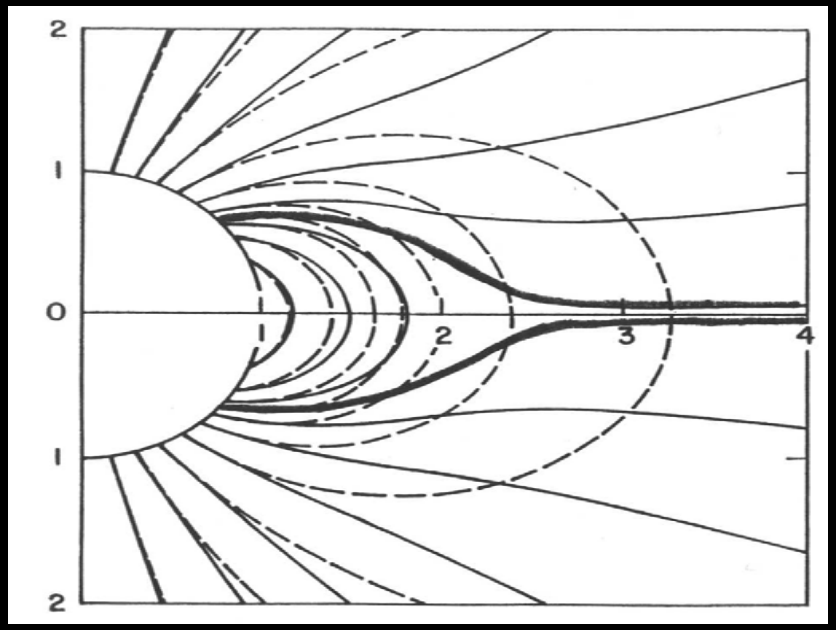


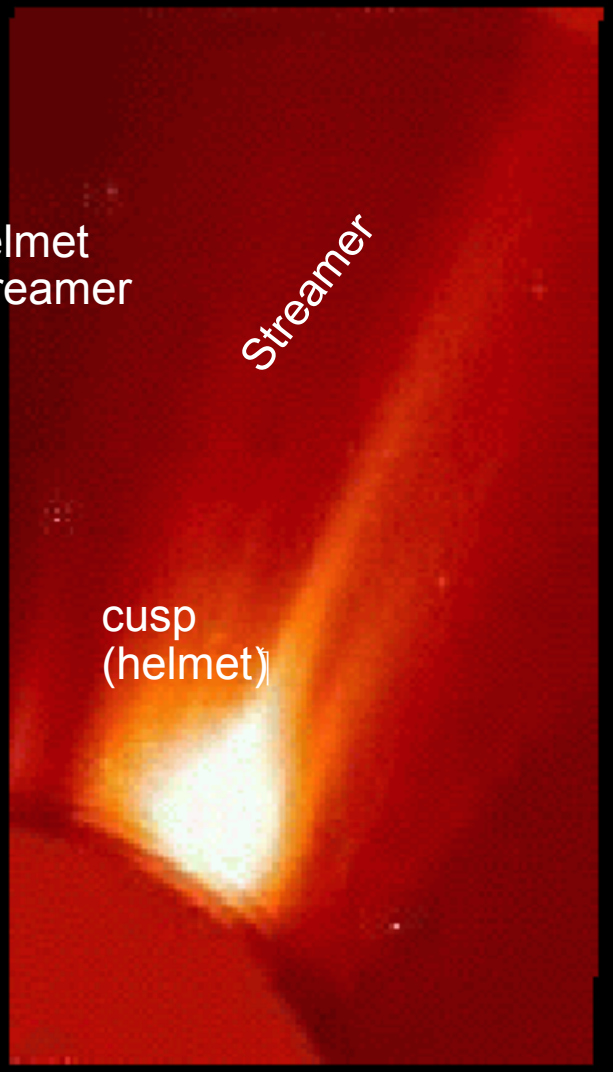
Coronal loop: Closed magnetic lines

Coronal holes: **Open magnetic field lines**

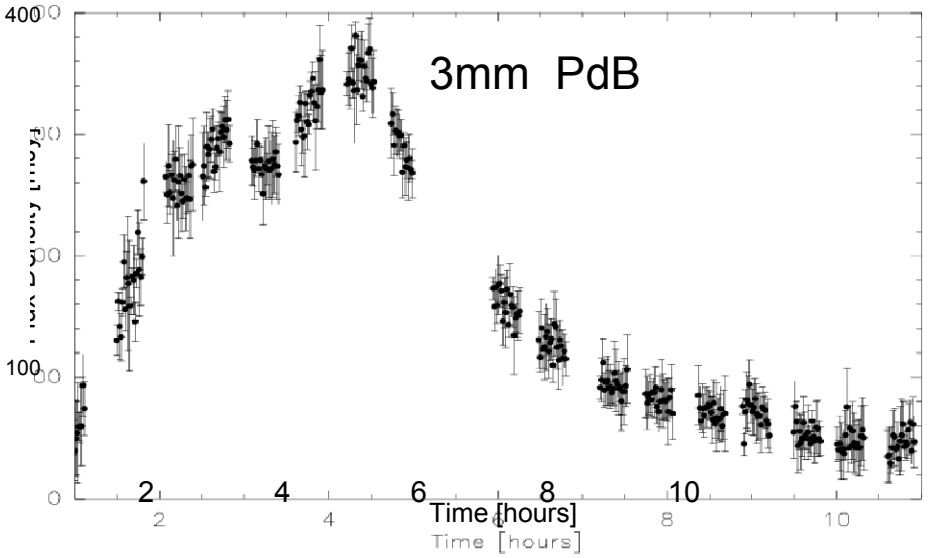


Open field lines converge above the top of the closed loops creating the "helmet"

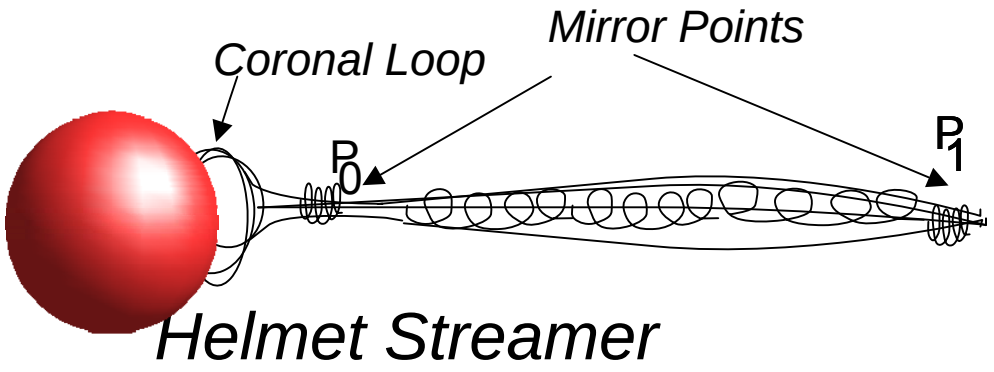




... and expand outward from the Sun (streamers) up to 30 solar radii.



Massi, Forbrich, Torricelli, Menten, Neidhöfer, Misuri,Bertoldi 2006

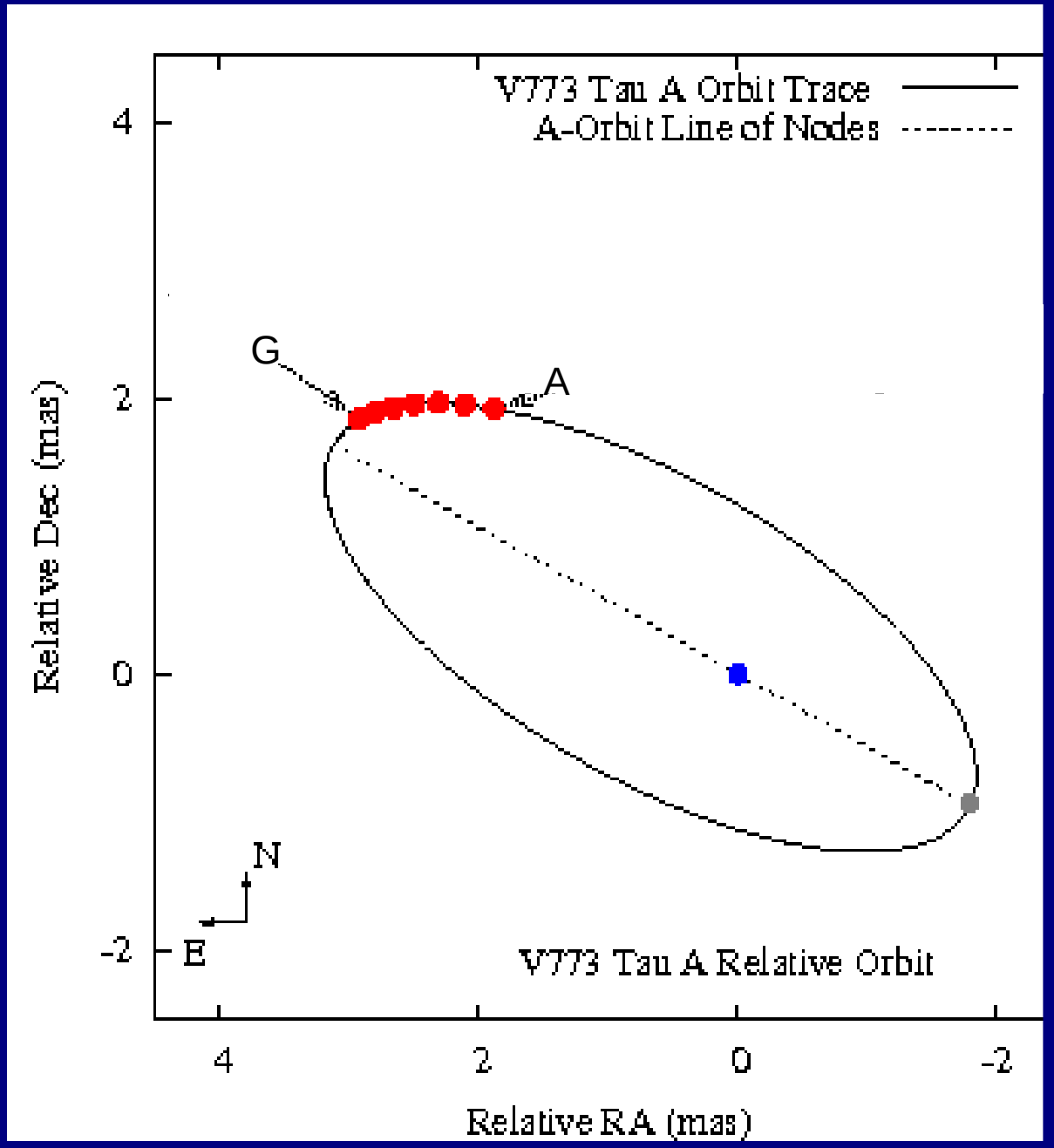


The flare decay (e-folding time of $2.31^{+0.19}_{-}$ hours) corresponds to a slow leakage of relativistic electrons trapped between two mirror points:

one close to the star (at 2-5 R_*) i.e. the helmet
and the other
at the top of the streamer (at 10- 20 R_*) i.e.where the two streamers interact with each other.

Effelsberg 100m-telescope

VLBA



Boden et al. (2007), Massi et al. (2008)

VLBA+Effbg

cm

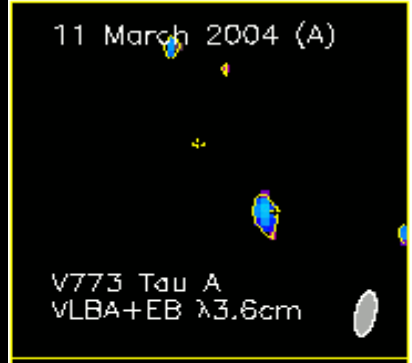
Beam size 1.3 x 0.5 mas

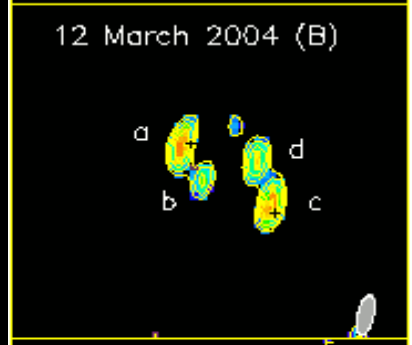
Apoastron:
52 R=3.6 mas

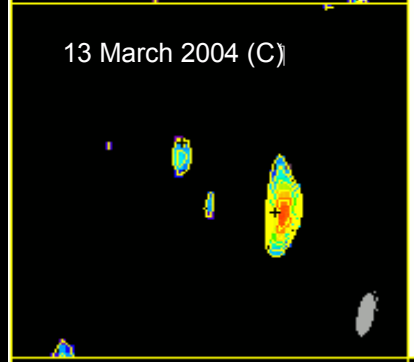
Periastron:
30 R=2 mas

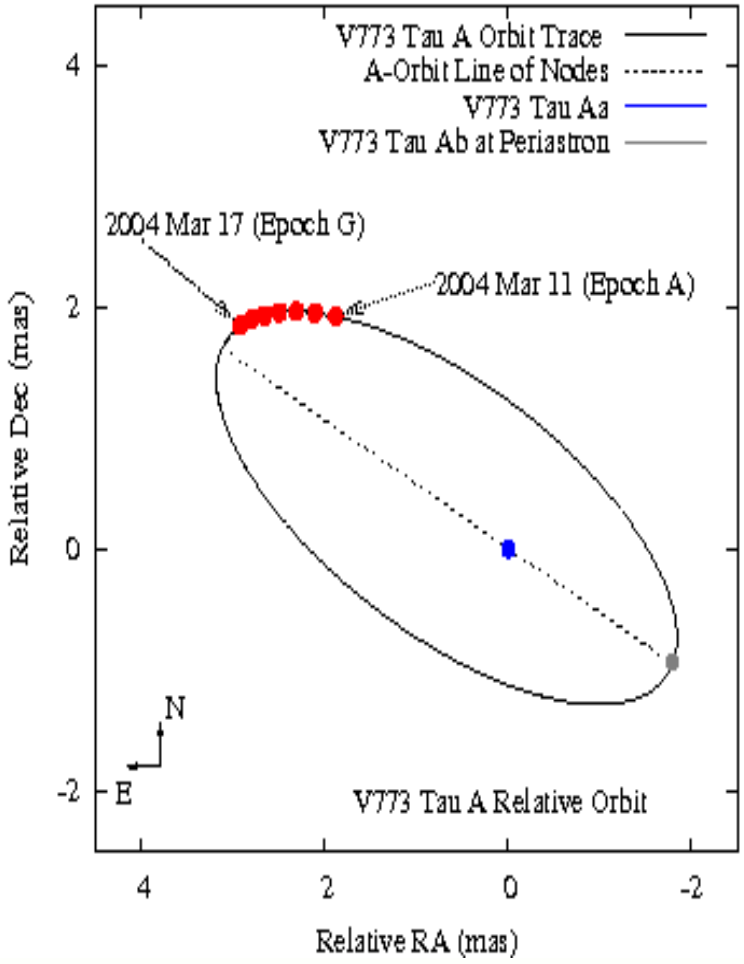
1 mas < H <1.8 mas

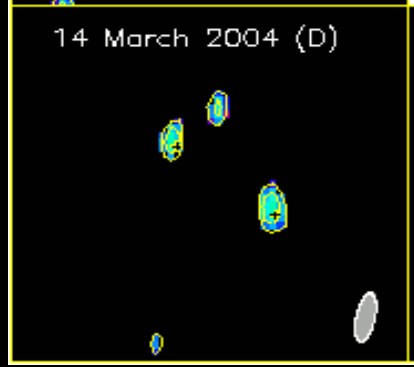
7days (A-G)
5 hours each

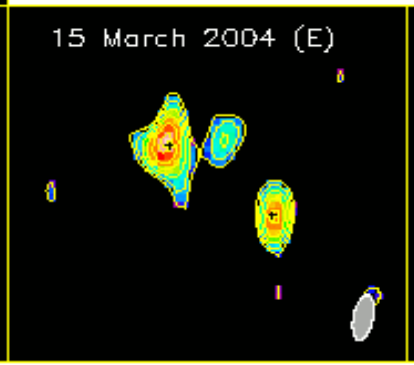


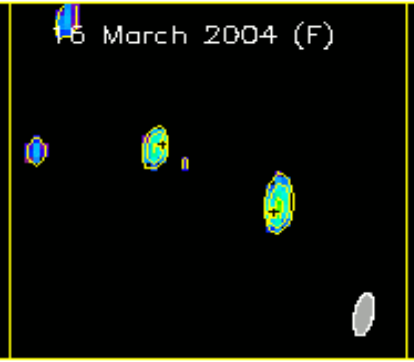


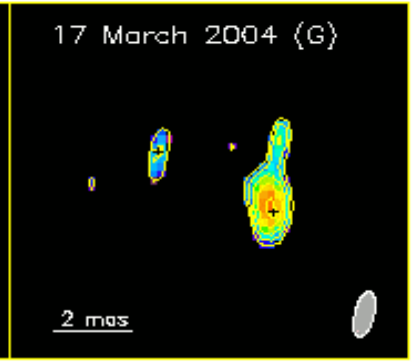








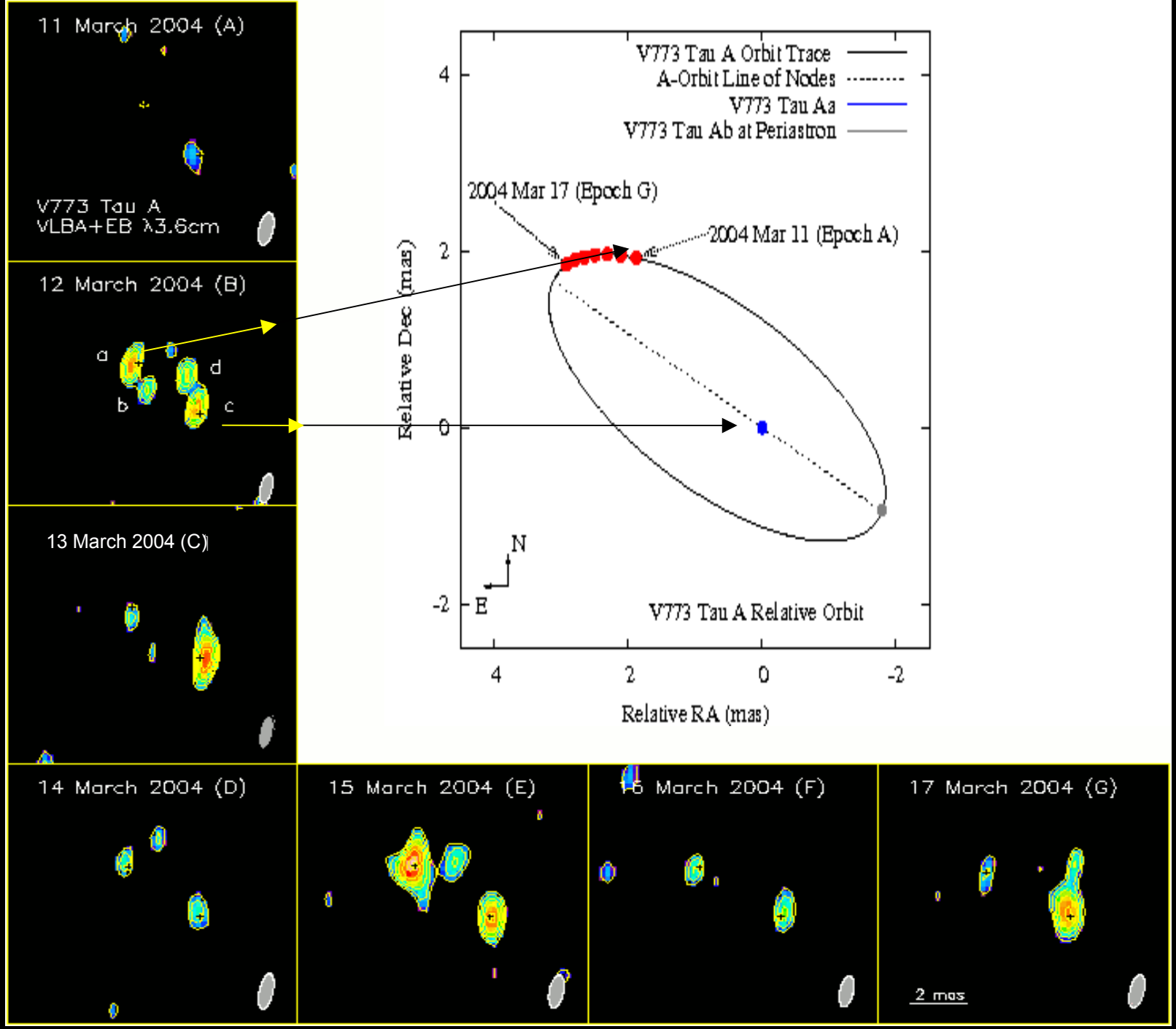




Two distinct structures appear in the radio images .

They happen to be associated to the secondary and primary star of the system.

Massi, Ros, Menten, Kaufman-Bernado, Torricelli-Ciamponi, Neidhöfer,Boden. Boboltz,Sargent, Torres (2008)



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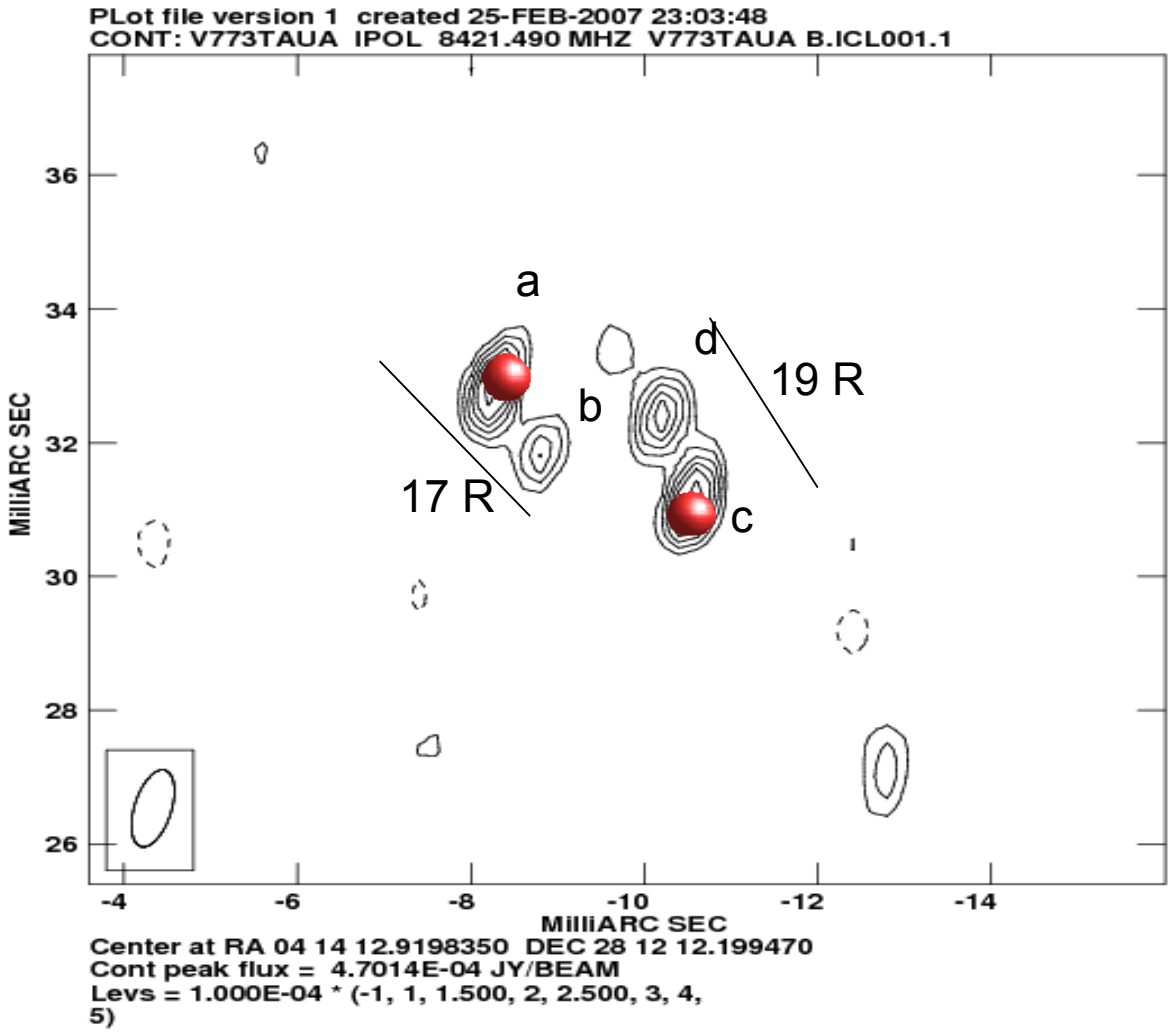
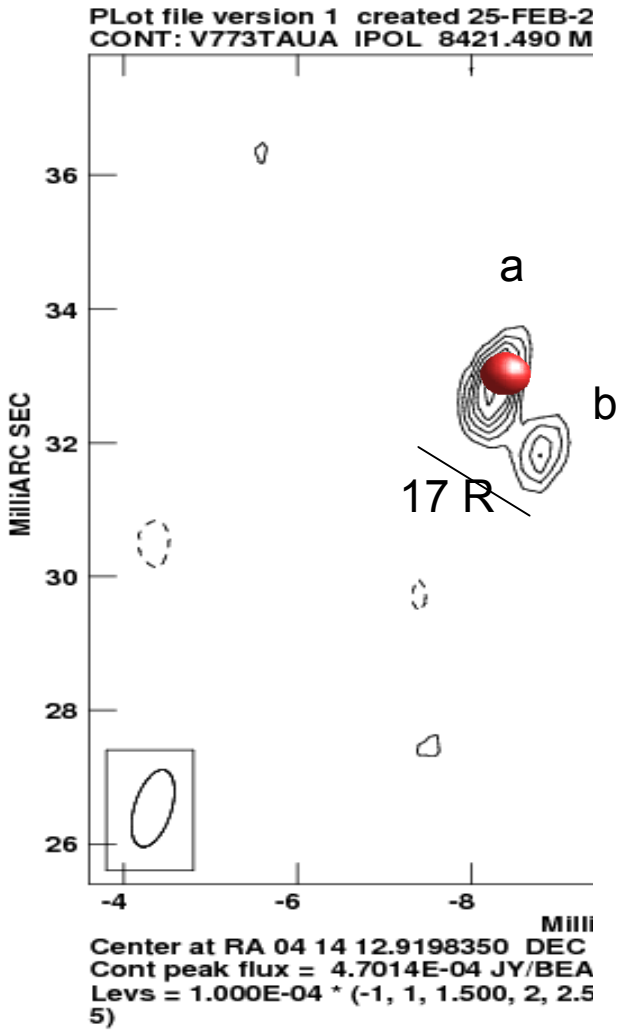
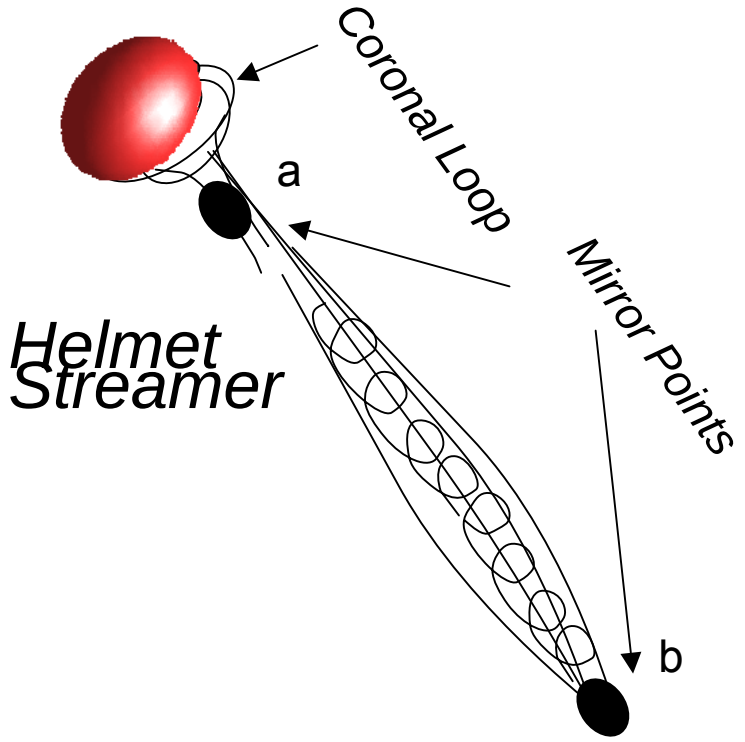
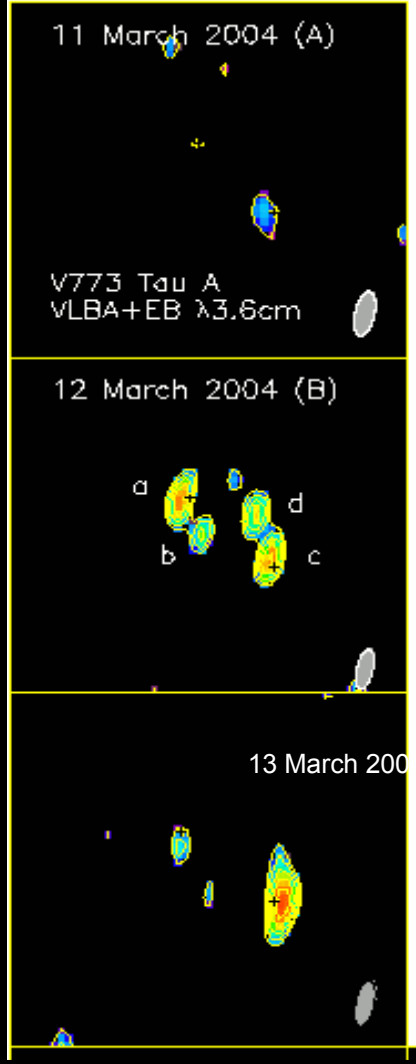

PLot file version 1 created 25-FEB-2007 23:03:48
CONT: V773TAUA IPOL 8421.490 MHZ V773TAUA B.ICL001.1
36
34
32
30
28
26
MilliARC SEC
-4
-6
-8
-10
-12
-14
MilliARC SEC
a
b
c
d
17 R
19 R
Center at RA 04 14 12.9198350 DEC 28 12 12.199470
Cont peak flux = 4.7014E-04 JY/BEAM
Levs = 1.000E-04 * (-1, 1, 1.500, 2, 2.500, 3, 4,
5)

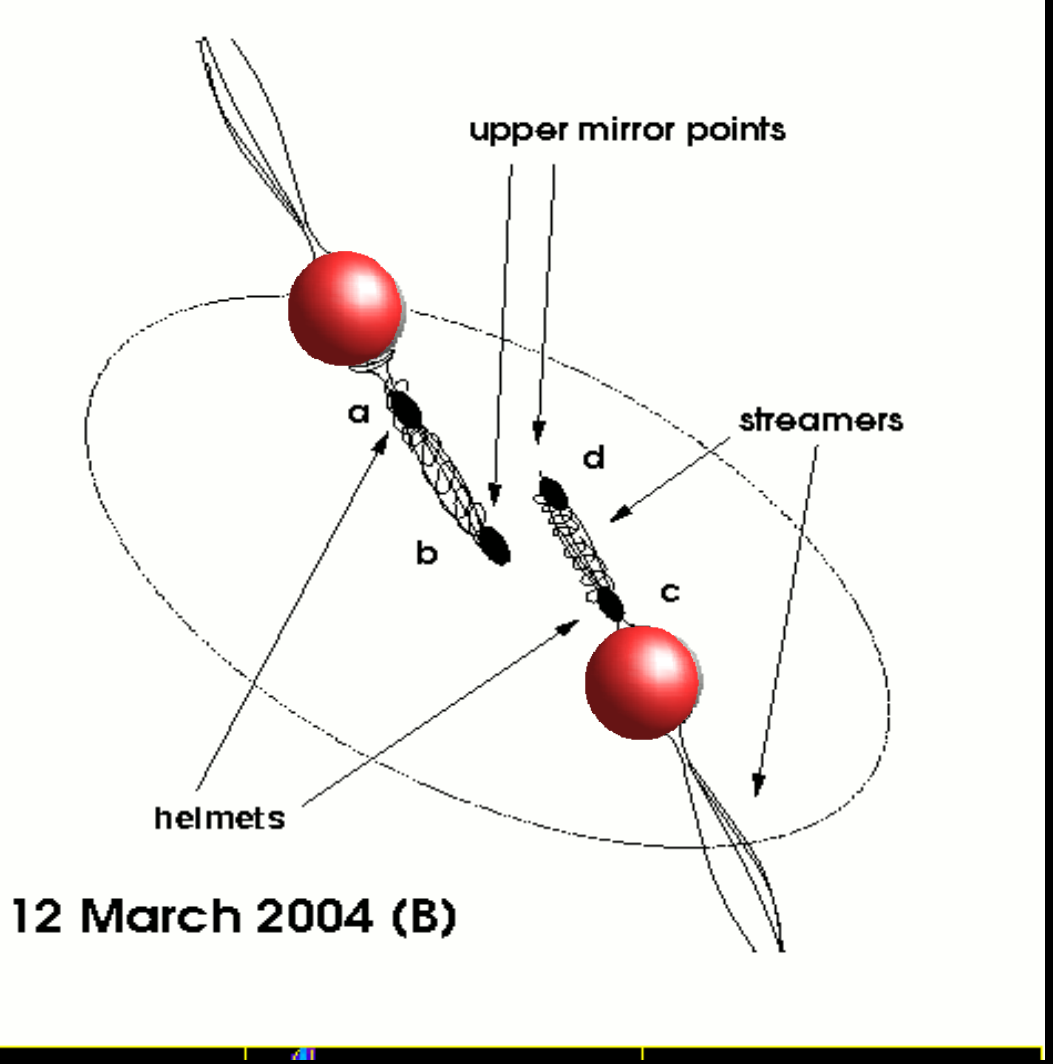
15 R < H < 26 R



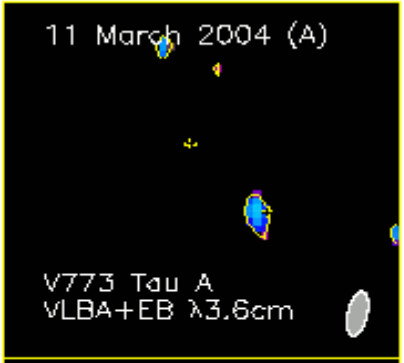


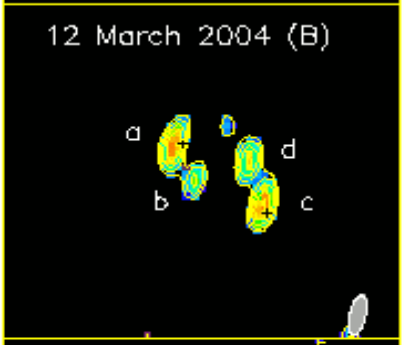
- Electrons, relativistically accelerated in the collision, emit synchrotron radiation, making the streamers „visible“ in the radio band
- Simulations predict the brightness peak of optically thin emission to be, where the magnetic field is stronger (i.e. at the mirror points) (references in Zhou et al. 2005)

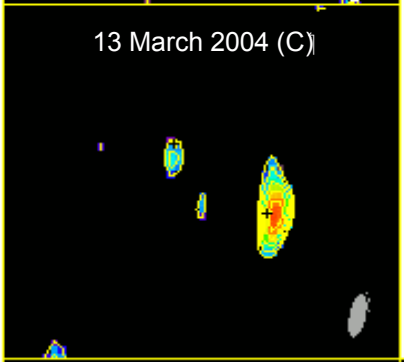


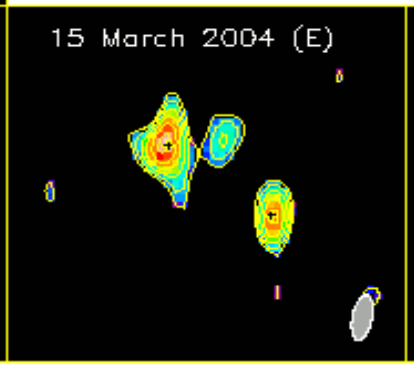


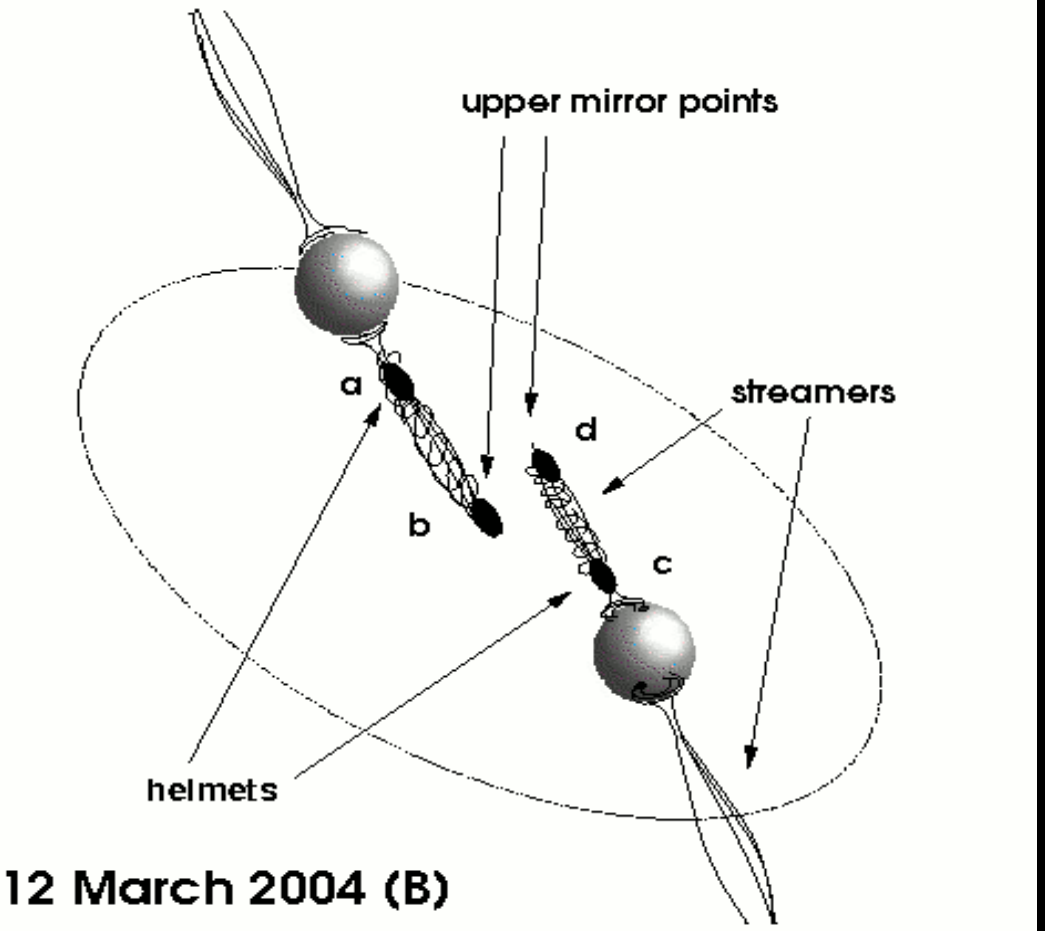
The two features, extended 18R each and showing both mirror points are almost lined-up **indicating two helmet streamers shortly after a collision.**



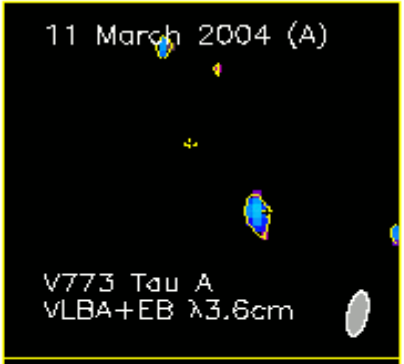


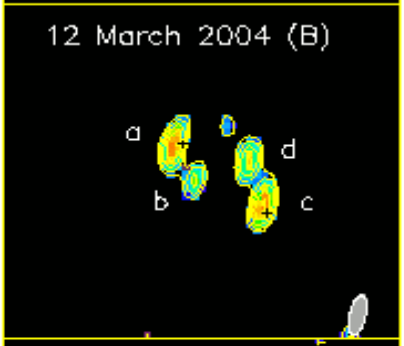


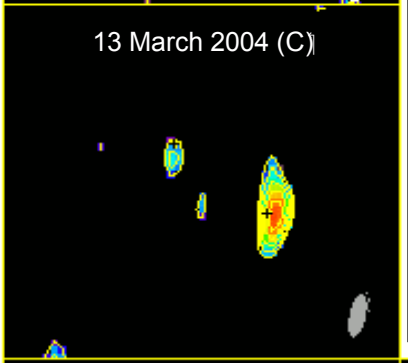


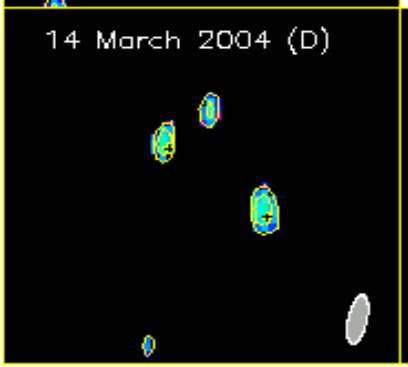


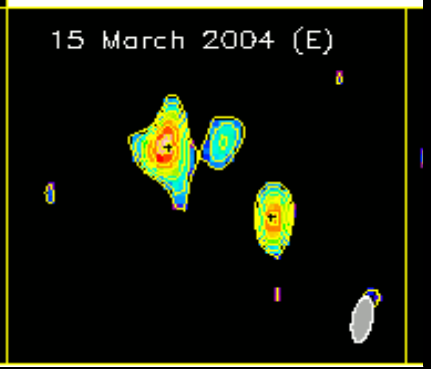
One image (run -E) taken a few hours after a flare (second the total flux monitoring at the 100-m Effelsberg telescope) show one elongated fading structure
substantially rotated with respect to those seen in the B run, as expected for an helmet anchored on a rotating star

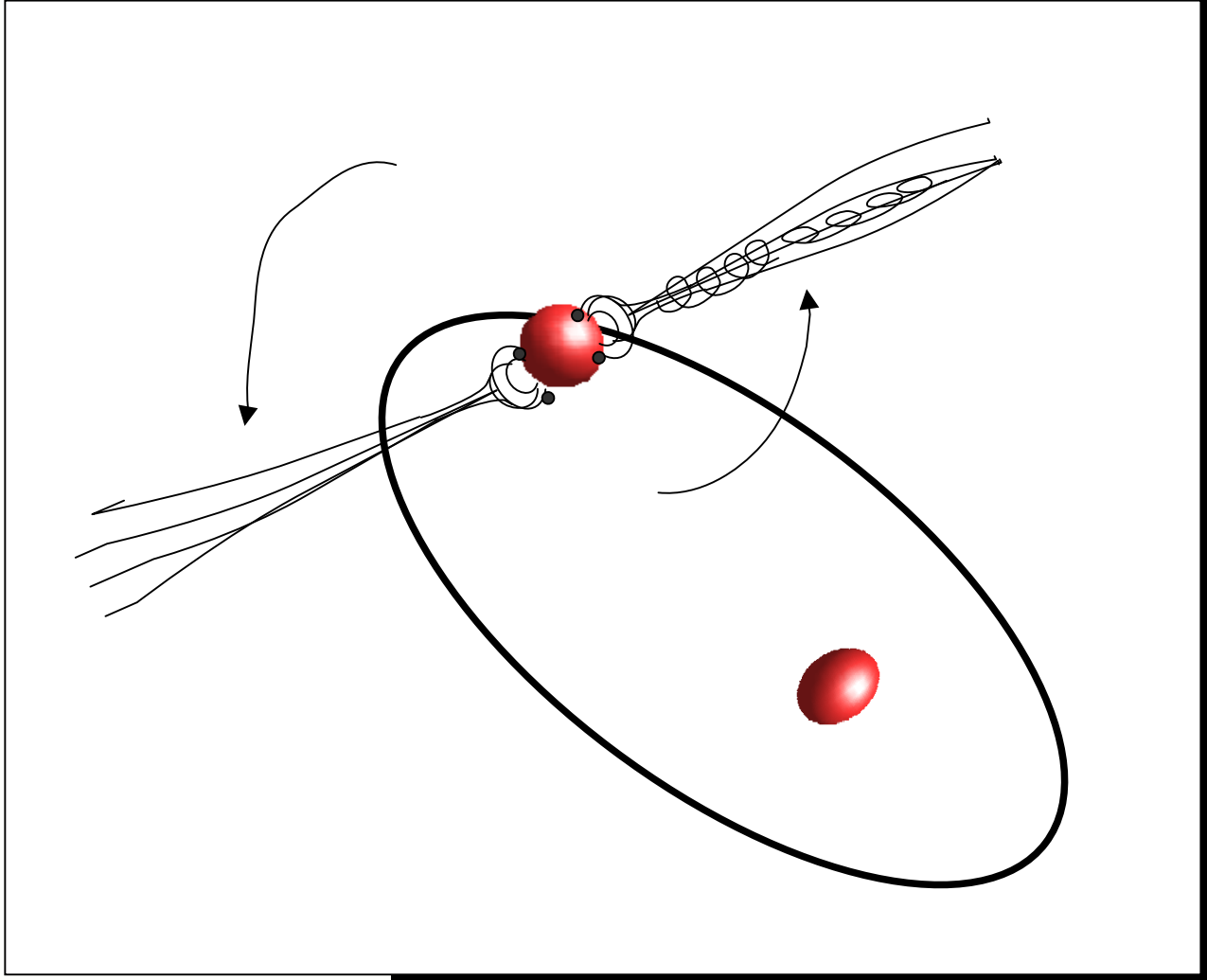






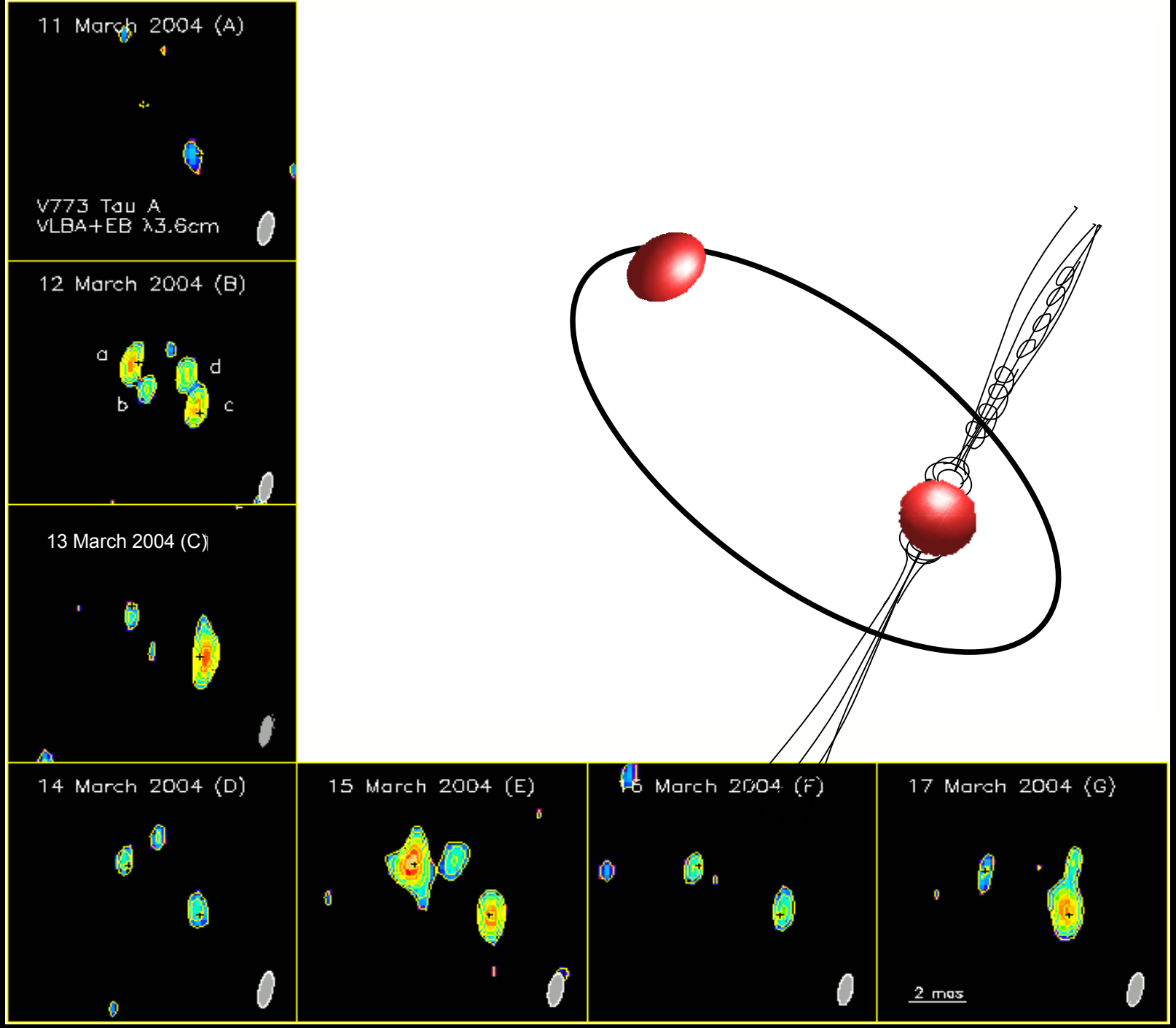






One image (run -E) taken a <u>few hours after a flare</u> show

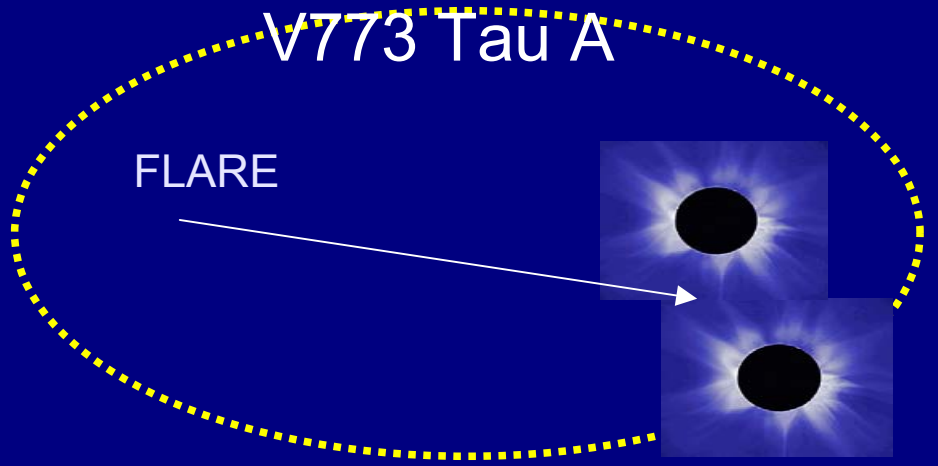
One elongated fading structure substantially rotated with respect to those seen in the B run, as expected for an helmet anchored on a rotating star (P~2 days)



The same rotation is seen in run G for the streamer associated to the other star.

Conclusions:

The factor triggering periodic flares in V773Tau is magnetic reconnection between streamers belonging to the two different stars.



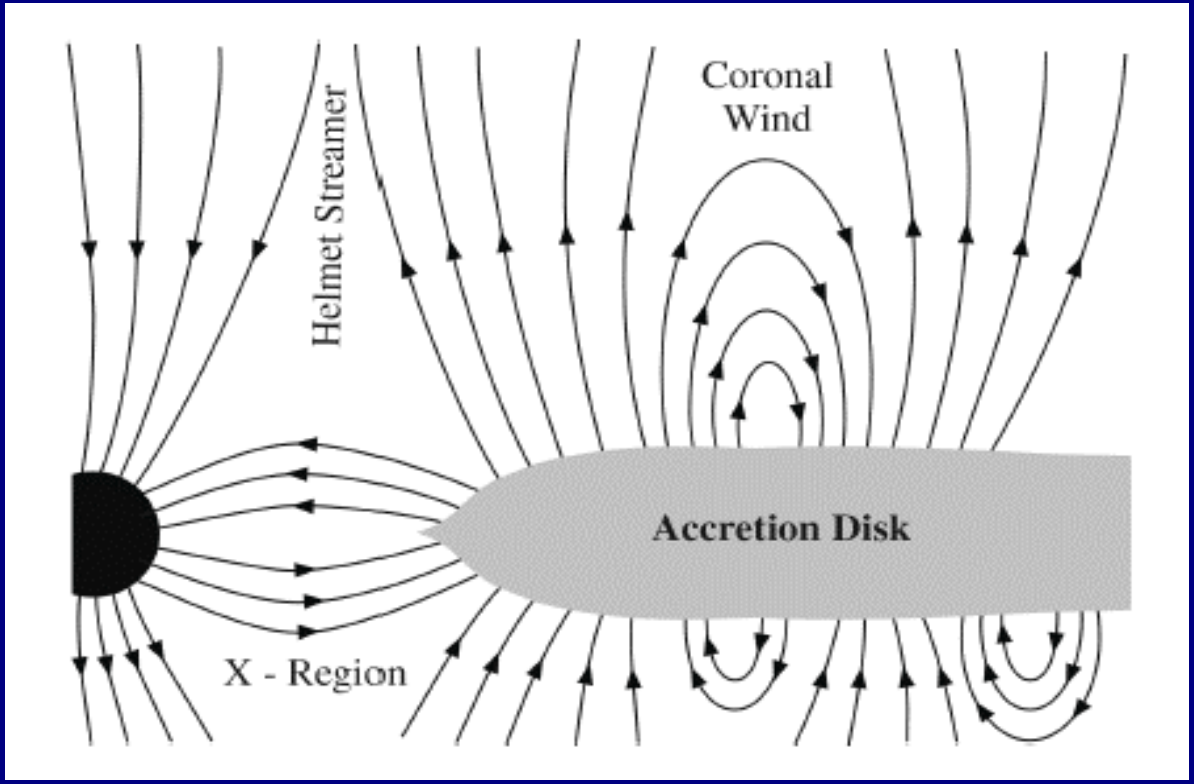
Interbinary collisions in a weak-line binary T Tauri system ----->>

1.

Helmet streamers are present also on fully/nearly fully convective objects

Phenomena associated to helmet streamers (Schwenn 2006)

- Slow wind
- "Blobs" or "Plasmoids"
- Violent coronal mass ejection



Bridging the Gap: Corona-Jet

Helmet streamers have been postulated to play a key role in the processes of jet formation in microquasars/AGN

(Gouveia dal Pino 2005)

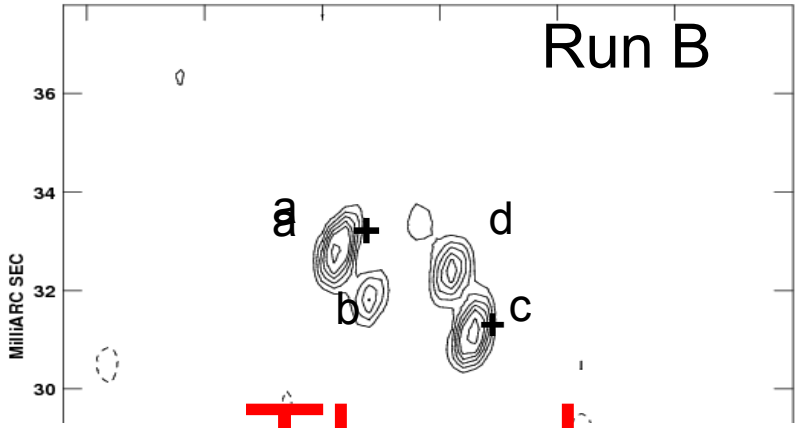
... and in outflows in young stellar objects.

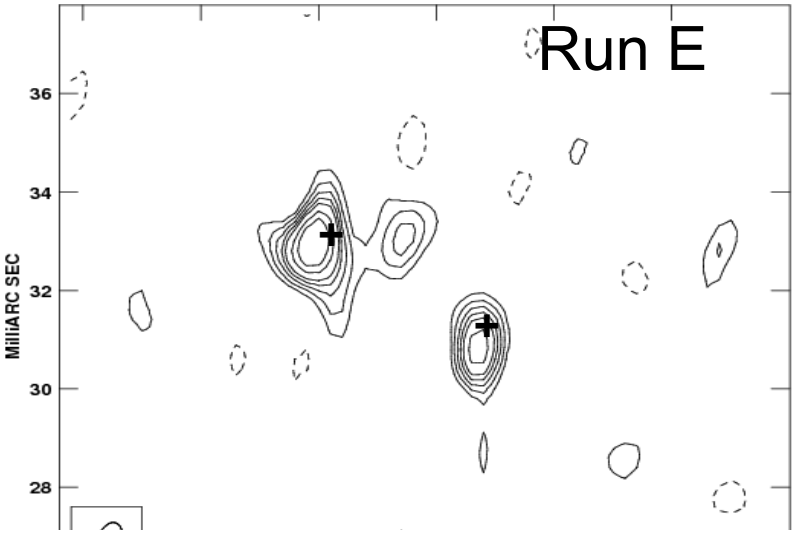
(Ostriker & Shu 1995; Ferreira et al. 2006).

Conclusions:

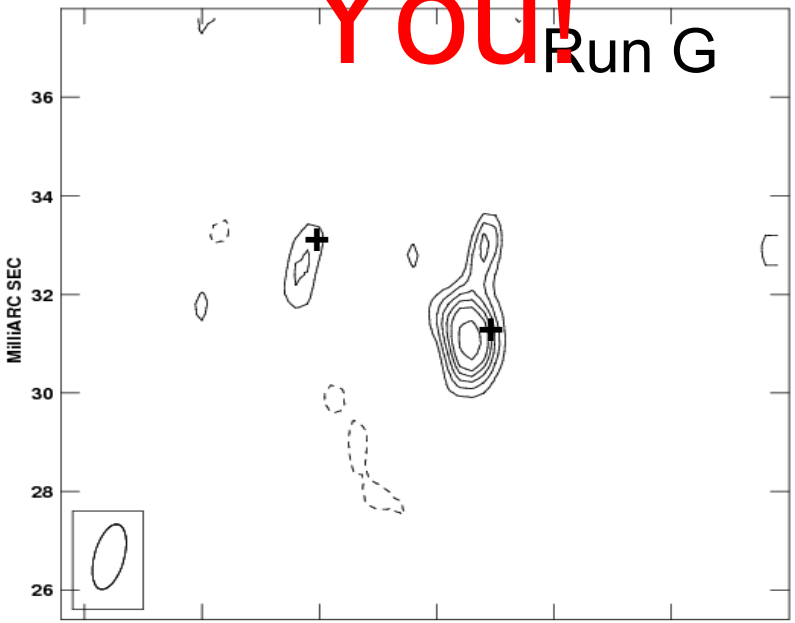
1. Helmet streamers are present also on fully / nearly fully convective objects.

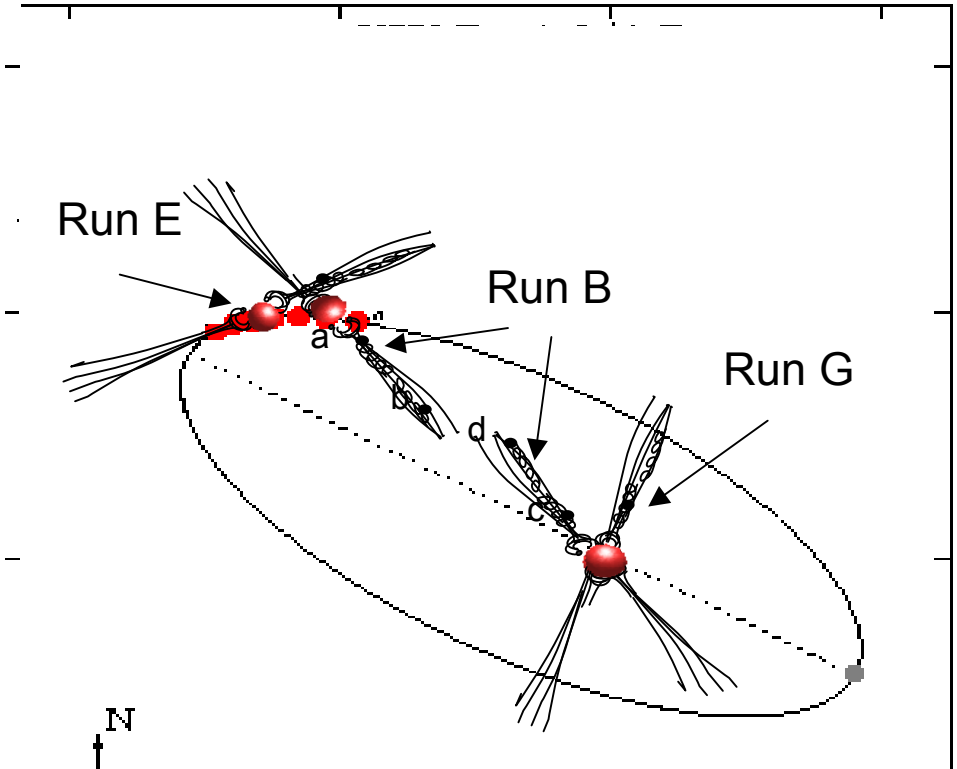
2. Their discovery in stars other than the Sun (at a wavelengt observable with high resolution) will therefore lead to a deeper understanding of these important magnetic structures.


Run B
MilliARC SEC
36
34
32
30
a
b
c
d


Run E
MilliARC SEC
36
34
32
30
28

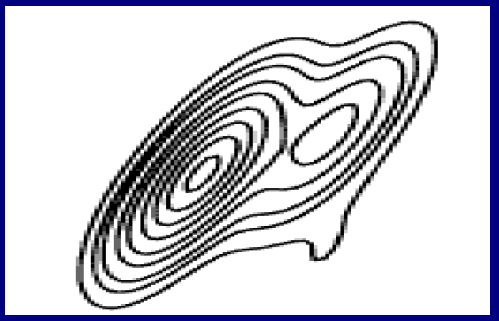
Thank You!

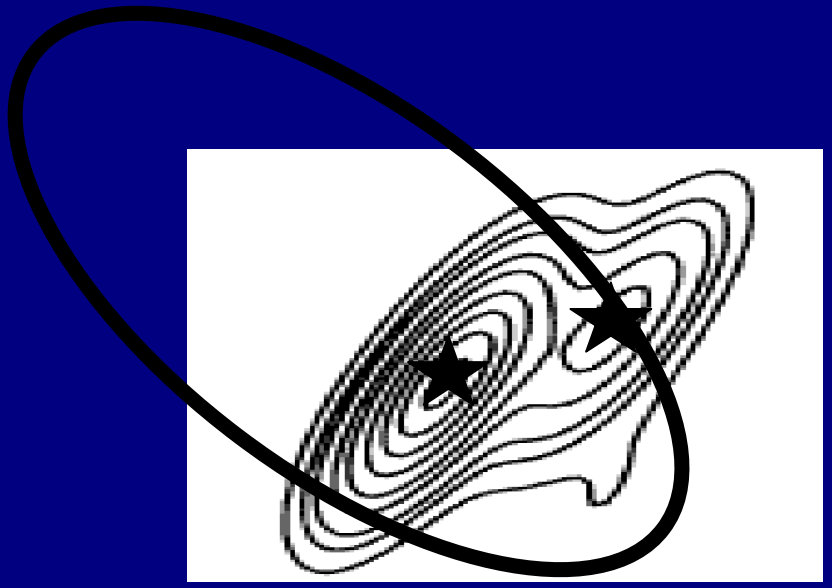

Run G
MilliARC SEC
36
34
32
30
28
26


Run E
Run B
Run G
a
b
c
d
N

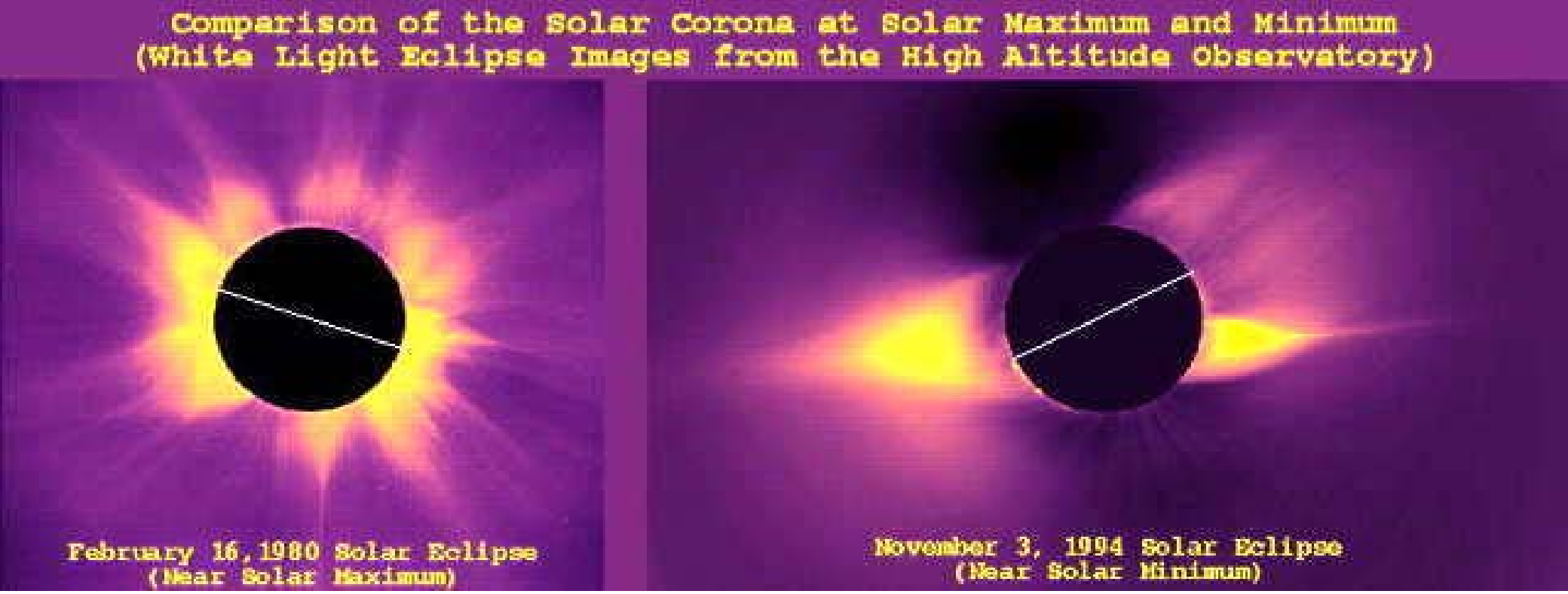
First VLBI image of the system

Phillips et al. (1996)





At the short periastron distance the two coronae nearly overlap, giving rise to the observed giant flares.
The result of such a situation, where the whole streamer participates in the magnetic reconnection process, is a large structure, which holds the emission peaks at the position of the two helmets anchored on each of the two stars as in the VLBI image of Phillips and collaborators (1996).



SOLAR MAXIMUM **SOLAR MINIMUM**

Light seen during solar eclipses (Maximum and Minimum):

It does not come from coronal emission but is photospheric light scattered from the coronal gas