CORONAL STREAMERS

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May 31, 1999

1 Introduction

1.1 General

The significance of streamers in the solar corona should be found in the frame of our knowledge of the slow solar wind and of the continuous dissipation of the large scale solar magnetic field in thin neutral sheets.

Geometric and thermodynamical parameters of streamers are measured during solar total eclipses and also with spaceborne coronagraphs. Different parts of a streamer, in the form of a helmet with a cusp or with a sharp edge and, further out, in the form of a stalk extended over many solar radii, should be considered. Accordingly, the modelling of streamers includes the analysis of effects produced by the solar wind flow on the magnetic structure.

Facts and arguments exist in favor of models with a current sheet and reconnection processes going on along the axis of the streamer, especially in the upper non-collisional part of the quasi-radially extended streamer. Further developments are needed to avoid difficulties occuring in the interpretation of a stationary solution, with possible inclusion of the large scale turbulence. Researches on streamers are planned with emphasis on observations done with spaceborne coronagraphs which permit a more extended evaluation of the non-stationary parts of streamers. These finer moving away structures are called detachments or blobs which are words to describe plasmoids (small outwardly travelling clouds of plasma without specifying their magnetic structure).

It is also noticeable that a large class of stars possess coronae, as evidenced by their X-ray brightness, which means stellar wind and obviously streamers are there present. Conversely, some theoretical models of the equatorial streamer-sheet are inspired by, or show similarities with, MHD accretion disks.

Figure 1: Caption 1.

1.2 Streamers, the large-scale solar magnetic fields and the solar wind

For more than a century, streamers were the main large structure observed in white-light (W-L) around the Sun during total eclipses. Their characteristic shape, see Fig.1 is a bulge-like wide body becoming narrower and being surmounted or prolongated by a very long and rather straight sheet or "stalk" first naively identified by observers as a large flow or stream of particles flying away from the Sun (the so-called "corpuscular radiation"), see Fig.2.

This interpretation however has not been fully confirmed. Streamers are quasi- stationary large-scale structures rising above filaments which overlay a magnetic polarity inversion- line (MPIL) dividing large unipolar regions of different signs. Further out, they are the result of a complex interaction between the surrounding solar wind and the large-scale magnetic field. Although in the early classical analysis of the solar wind processes by E. Parker the flow essentially avoids streamers, the magnetic field is obviously also transported inside streamers which are definitely open structures at large distances.

Later on, a first theoretical account of this effect was attempted in the early 1970 by Pneuman and

Kopp. The formation of a current system with a slow dissipation of the solar magnetic field was considered responsible for maintaining such an overall structure over many solar radii and several months. Accordingly, streamers are also good candidates for explaining the origin of the interplanetary magnetic field (IMF), including the helio-sheet which means they are the most probable source of the slow wind.

The global structure of the corona has been known for a long time, although, no concrete account of it is made in the classical theory of the acceleration of the solar wind, nor in the theory of the extended coronal heating. In addition, there are many fine structures see in [1], which eventually clump together to form a larger scale structure. Starting from the surface, fine-scale streams are more and more stretched out; for some reason, sometimes they form a twisted sheet. Apparently a converging end (cusp) is sometimes observed and this part of the streamer is called a helmet. It is not excluded that the cusp is just a projection effect due to the overlap of a partly wrapped sheet along the line of sight. Further out, a long slightly diverging stalk is observed. The whole structure is called a helmet streamer.

In case that the solar underlying region was occupied by a group of active spots, it may be said that the magnetic activity is transmitted outwardly. In soft X-rays (SXR) or in the optical green line of Fe XIV (a forbidden line at 530.3 nm formed at a ionic temperature of 2 10^6 K) for example, big loops rising up to 10^5 km heights are seen. They look similar to arches seen higher in W-L in the low part of the body of the streamer. In case of a matured streamer, the body is definitely on the side of the old active region. Often at a low level near the bottom of the streamer, a cavity is seen right over a low lying prominence (a dark region surrounding the prominence suggesting some coronal plasma is missing in its neighboring). The prominence reveals the MPIL but it is not clear what the cavity is made of. Because the cavity shows overlapping dark loops, it suggests that it is due to coronal magnetic fields evacuating some parts of the low corona in the vicinity of the filament.

Closed magnetic configurations have naturally been proposed at the base of the helio-sheet surrounding the Sun at solar minimum of activity. However, streamers are not yet observed at distances from the Sun large enough to make the connection with the IMF, including the location where the IMF changes of sign. There a dense and low velocity flux of particles is observed, with a ratio of heavy particles 2 to 3 times lower than in the average wind. Coronal holes which are open parts in the corona, and coronal mass ejections (CMEs) are both considered as the main sources of the fast wind. In streamers, the density is clearly higher; however they occupy a rather small volume in 3-D as evidenced on 2-D images showing the stalk or the sheet in projection. So, their contribution to the mass loss is not well defined. This conclusion certainly depends on the level of activity. In coronae of active late-type stars, the contribution of streamers to mass loss could be very large.

1.3 Coronal streamers seen from groundbased (G-B) observations and from space

Outside of eclipses, streamers are also seen in radiowaves, at least their lower part, below 0.5 solar radii (R_o) from the surface. In space, this part is seen using soft X-rays telescopes (SXT) and extreme-UV telescopes (EUVT). However, streamers should not be confused with enhancements occuring above active regions and plages. The same is true for K-coronometer data (the polarized continuum measured around the Sun using G-B Lyot coronagraphs like the one operated at the Mauna-Loa Observatory) or for Fe XIV data plotted on a synoptic map (this is done routinely in Observatories like Sacramento Peak Observatory). At meter wavelengths, the thermal brumsstrahlung emission of streamers shows a brightness temperature higher than outside by 10 to 30%. Furthermore, radio-heliograms show radio-burst activity of type III propagating inside streamers confirming the idea that a current sheet develops inside.

Although the feet of streamers are often confused with enhancements, especially in equatorial regions, streamers are more radially extended structures only seen on large field images. Using balloonborne and recently spaceborne externally-occulted coronagraphs, streamers and their co-rotation with the photosphere have been extensively observed above $1R_o$ from the surface. These observations are fundamental in providing an extended data set to analyze their temporal behavior, although the 3-D viewing is still missing. Missions to supply a stereo-view of the corona are planned.

In the future, in-situ measurements will be made with a solar probe crossing streamers close to the Sun yielding magnetic field measurements which are very much needed to progress in their modelling. At the moment, we are still forced to speculate being inspired by results coming from the analysis of the Earth's or Jupiter's magneto-tail which can be regarded as a more simple prototype of cosmical plasma phenomena occuring inside streamers where in-situ measurements are available.

Figure 2: Caption 2.

2 Parameters of streamers from W-L observations

2.1 Evaluation of observations

Total eclipse observations offered a good way to extract the parameters needed for models. Several solar cycles have been covered. Space born W-L coronagraphs of the SoHO mission (LASCO experiment) are now providing additional data. The analysis of streamers requires the following features:

a/ Photometric accuracy: absolute calibration is needed. The one million times attenuated image of the solar disk or, better, images of the seeing disk of calibration stars obtained simultaneously with the image of streamers, are used to perform a precise 2D photometry.

Additionally, a precise quantitative polarimetry is needed to take into account the fact that in W-L, polarization due to Thomson scattering is strictly radial.

b/ Spatial resolution: radial neutral filters should be used to optimize the signal/noise ratio over the image of the corona and help the analysis of sharp edges of streamers in an effort to deduce the 3D distribution of densities.

c/ Field of view coverage: both the inner parts of the coronal streamers and the external parts, up to 10 and more solar radii, should be studied. At G-B the sky background due to multiple scattering in the Earth atmosphere is a limiting factor; in space the instrumental scattering is critical. Airborne eclipse images were successfully collected by the Los Alamos Laboratory group during more than one solar cycle with a large field of view, (see Fig.2), showing a representative set of streamers' images.

The main parameters of streamers are still coming from the large number of eclipse observations accumulated by many authors. Regarding the solar minimum helio-sheet, SoHO data are of great interest as several years of observations are now available.

2.2 Geometric and thermodynamical properties

2.2.1 General aspect

The first part of a streamer starts somewhere in the low corona; it is often described as a bulge or helmet, see Fig.1, part A. This part is typically extended up to $1.5R_o$ from the surface and its 3D structure is not at all clear with sometimes a cusp at the top and more often, without any cusp.

An other interesting feature is the sharp edge of the streamer which is sometimes well enhanced, see at the top of Fig.2. In reminding that the W-L optical thickness is completely negligeable, a straightforward interpretation of this effect is to say that the streamer is made of a thin wrapped sheet.

At high latitudes, the enhanced edges of streamers can be confused with individual polar thread-like structures ressembling to plumes. When the system of sheets is developed along a filament channel or a MPIL at low latitudes, their projection on the sky can give the impression of a gaussian-shaped cross-section, especially at low resolution. It is an effect due to the overlapping of many components. At solar minimum of activity, the streamer equatorial belt can become extremely narrow at large distances, although the body of the streamers is rather large.

Thanks to the polarization analysis, the cross-section of streamers was investigated, confirming the belt-like distribution even at moderate latitudes. The width and radial extension of the body of a streamer is related to the phase of the activity cycle: at maximum of activity, it is smaller and narrower.

2.2.2 Radial extension

From the analysis of many eclipse pictures taken during the last 4 or 5 solar cycles, it has become evident that streamers do not extend precisely in the radial direction, see Fig.2. The average deviation from the radial direction of the upper parts (stalks) is also a function of the activity cycle. However, streamers are clearly stretched out by the wind whose influence is growing with the radial distance. This is strongly suggested by the absence of prominent curvature in the stalks and the occurence of many fine thread-like well aligned structures inside the stalk.

2.2.3 Cross-section and width

From the photometric analysis of many large streamers, see Fig.1 and 2, we convincingly see that all streamers are diverging starting from a radial distance of order of $2R_o$ from the surface. This part of the streamer is called the neck, when making the assumption of a circular cross-section, which is an oversimplification.

There are good reasons to claim that the real cross-sections of streamers are closer to that of curved sheets. The polarimetric analysis in W-L suggests that they are rather extended along the line of sight, although in projection they can look quite narrow. More often, one edge is well enhanced and shows a discontinuity with a large gradient measured accross this discontinuity which means in a direction almost orthogonal to the radial direction (see B in Fig.1). A strong jump of plasma density is then occuring, related to the thickness of the sheet and its curvature. The gradient across the discontinuity is typically 2 orders of magnitude greater then the radial one, demonstrating the importance of the magnetic field there.

A more complete description of the details inside the streamer would include the analysis of thread-like structures which is of great interest to understand the structure of the magnetic field and interactions plasma-magnetic field.

2.2.4 Electron densities

Photometric measurements of eclipse pictures in W-L provide a measurement of the average electron density $< n_e >$ in streamers close to the value of the plasma density, provided the abundance anomalies are neglected.

Let us assume that the brightness $I_o(r)$ of the spherically symmetric background corona is removed from the measurements. The contribution $\Delta I(x)$ of the streamer intensity at its maximum of visibility in the plane of the sky and a distance x, can be quite simply expressed as a function of the density:

$$\Delta I(x) = \sigma W(r) < n_e > l(r) \tag{1}$$

All intensities are taken in units of the average brightness of the solar disk; σ is the Thomson scattering coefficient considered isotropic in first approximation; $W(r)$ is the dilution factor of radiation taking into account the limb darkening of the solar disk. With some simplications we take $W = ar^{-2} + b(r)$ with $b << a$ for $r > 2R_o$. All radial distances r are in unit of solar radii R_o and a and b are known coefficients depending of the wavelengths. .

Assume for the purpose of the analysis a circular cross-section; then the length of the line-of-sight integration is $l(r) = FWHM$, where $FWHM$ is the measured photometric full width at half maximum. The average electron density is then readily obtained from the photometric analysis, provided the position of the streamer in space is known. A first approximation is to consider it close to the plane of the sky, then $x = r$. Further, a position angle can be deduced from the polarization analysis or better, from a synoptic view using several days of observations (spaceborne observations) and following the streamer during its rotation with the Sun. This is especially efficient when the stalk of the streamer is well isolated at high latitude (see the streamer C in Fig.1).

Obviously, a stereo-view of the streamers would also permit a better evaluation of their 3D structure.

Considering densities in the lowest parts which correspond to the body of the streamer (first radii above the surface), equation (1) is not of great help. A model of the body should be considered with e.g. a cylindrical wrapped sheet with a sharp edge (discontinuity) or with a more linear extension of ellipsoidal and gaussian shaped cross-section. On each eclipse picture several streamers can be studied with these methods and the results differ slightly, partly because the photometric accuracy is limited. However, a real dispersion in densities is observed, mostly connected with the geometric complexity which is introduced in the analysis, as no filling factor is used (remember that streamers are made of overlapped thin curved sheets and threads). For large streamers a radial variation of densities is plotted on Fig.3. Densities are found to be significantly higher than the mean densities deduced by smearing all structures in the volume in order to make an axisymmetric, homogeneous model of the corona; they are also smaller than densities deduced for a really small cross-section ray or thread. For $r > 2R_o$ they are typically 2 orders of magnitude higher than densities in coronal holes where a large flow is known to exist. It makes streamers very interesting 3D topological objects to study.

Figure 3: Caption 3.

2.2.5 Temperatures in streamers

From the radial gradient of densities, a temperature can readily be deduced, assuming hydrostatic equilibrium (see Fig.3), at least in the body. This means that the flow there, if it exists, is negligible, the temperature is uniform enough, and finally the radial component of magnetic forces is weak.

Assuming that μ, the mean molecular weight of particules in the streamer, is known from the consideration of abundances and ionization degrees (H and He are fully ionized, so in first approximation $\mu = 0.6$), M_h being the mass of a proton and g the acceleration of gravity at the surface of the Sun, we have:

$$n_e(r) = n_e(R_o) e^{-(\mu M_h g R_o / kT)(1-1/r)} \qquad (2)$$

with $n_e(R_o)$ being the coronal density at the surface. The deduced values, (see Fig.3) are between 1.3 and 1.6 MK (10^6 kelvin). These values are in good agreement with values expected for ions as deduced from ionization balance analysis. There are systematic observations of e.g. the FeXIV 530.3 nm line emissions at the base of streamers, especially at low latitudes and we know this line is formed between 1.4 and 2 MK. The red line of FeX at 637.4 nm formed near 1 to 1.4 MK is also sometimes observed in streamers.

Flux values reported from radio-waves observations are more ambiguous to interpret and it is difficult to compute the temperature due to their sensitivity to both densities and inhomogeneities which refract waves. Finally, observations in SXRs also nicely show arch systems at the base of streamers, especially above filament channels and MPIL. In SXRs the contribution function describing emissions is situated in the range of 1 to 3 MK, which covers the temperature of streamers. In conclusion, both the hydrostatic equilibrium temperature and the ionization equilibrium temperature agree well, giving a value close to 1.5 MK in the body of the streamer.

Further out in the stalk, more observations are needed since even the sign of the radial temperature variations is not known. This is a question related to the problem of the efficiency of heating inside streamers.

3 The Modelling of coronal streamers

3.1 Position of the problem

A great amount of observational material has been accumulated on streamers, based on eclipse observations and spaceborne W-L experiments which are still less accurate, but these are vastly more extended in temporal coverage. During the last years, many studies were devoted to the analysis and modelling of CMEs, a clearly non-stationary phenomenon. Streamers are then considered separately as part of the background, or interacting with the CME or being even part of the CME. Both phenomena are dynamical and clearly related.

A model for streamers should consider the complex 3D-geometry of the structure and the physics of the collisional plasma becoming non-collisional further out, with a sharp and non-monotonic variation (with respect to radial distances) of velocity, of magnetic field and of the ratio gas pressure to magnetic pressure called the β of the plasma. The use of large computers help in modelling streamers, starting from the surface of the Sun, over a large interval of radial distances, including the connection with the IMF. However, there are specific questions related to the physics of streamers which need a discussion of the classical work of Pneuman and Kopp, see [2] [3].

3.2 Global effect of the wind on the magnetic field

The general process of quasi-stationary expansion of the corona is due to large-scale magnetic structures emerged from the deep convection zone and dissipating during long time intervals, up to several months. Streamers are the result of the stretching out of the magnetic field of those structures by the solar wind.

Indeed, in the body up to $2R_o$ from the surface, the corona is close to hydrostatic equilibrium, as was already conjectured by Alfven in the early 1940-s and well confirmed by many works. In those parts of the corona, the influence of the gravity is dominant and determines the radial gradient of the gas pressure. Higher up in the corona, the decrease of gravity induces a radial flow corresponding to the hydrodynamical expansion of the corona. Density gradients orthogonal to the main direction of structures are overwhelming radial gradients see 2.2.3.

The role of the wind to transport magnetic fields into the interplanetary medium is evidenced from the consideration of a simple theoretical treatment assuming first a dipolar magnetic field and the surface of the Sun as the source of the wind. Outside the surface, $\tilde{B}$ is found from the solution of the well-known hydromagnetic equation:

$$\frac{\partial \tilde{B}}{\partial t} = rot\tilde{v} \times \tilde{B} + \eta \Delta \tilde{B} \tag{3}$$

with $\eta = \frac{c^2}{4\pi\lambda}$ the magnetic viscosity (or diffusivity), $\tilde{v}$ is the flow velocity, and λ is the conductivity, considered constant.

Taking also the velocity constant, and without considering the rotation of the Sun permits to readily solve the equation. Using an iterative method, it is possible to take into account variations of v, etc. Magnetic configurations with different magnetic Reynolds numbers $R_{em} = v \times \frac{L}{\eta}$ are computed; L is the characteristic length in the streamer. When R_{em} increases, lines of force are more and more stretched out, which means they become more radial in the equatorial plan. The streamers are carried away to large distances but stay closed in equatorial regions which would mean that they never become open nor divergent as observed.

A more realistic approach is to consider a model by introducing a so-called source-surface situated somewhere between 1 to 3 R_o from the surface; inside this surface, no motion is assumed; beyond, only a radial magnetic field is considered, which is carried away by the wind. This empirical model easily explains the global distribution of the IMF but no physics is proposed, without saying that the source-surface has any observational counterpart.

Figure 4: Caption 4.

3.3 Models with a current sheet

It is clear that a simple model with a current sheet should include geometrical effects and the sheet-like nature of the streamer belt overlying the MPIL, with a rather large density enhancement occuring inside the sheet. This confinement of the plasma in the sheet is quite similar to what is known to occur in the case of the prominence material ('curtain-type'). Accordingly, an analytical model inspired by the classical Kippenhahn- Schluter model of prominences can be worked out. In the case of the corona, spherical symmetry is used and several additional assumptions are made: axisymmetry, negligible dynamical effects (compared to the magnitude of magnetic forces) and a simple magnetic configuration providing the confinement in a sheet. Solutions are then coming from the consideration of the well-known Grad-Shafranov equation modified to include forces due to the gravity :

$$\nabla p - \frac{j^*}{cr\sin\theta}\nabla\Psi + \rho\nabla\Phi = 0 \qquad (4)$$

where Φ is the gravitational potential and Ψ is a flux function permitting to compute the magnetic field following some known relations where electric currents $\jmath^*$ are given explicitely. The free parameters are chosen such that the plasma density ρ and the temperature in the streamer which determine the pressure p, set stringent constraints. The configuration of the resultant magnetic field differs depending on the sign of the currents in the sheet. Details of the treatment and the discussion of different solutions are usually done numerically. Figure 4 is an illustration of the set of magnetic field lines obtained by M. Molodensky for the 2 typical cases readily deduced, depending on the thickness of the sheet: (a) at left is the classical solution of the Pneuman- Kopp type coming immediately from this treatment; (b) at right is the solution corresponding to a well confined thin equatorial sheet.

The narrow distribution of densities inside the streamers is now possible in form of a sheet (or blade) although the coronal magnetic field inside the sheet is open (lines can be closed somewhere at very far distances): it is a "concave shape current sheet". Note that the classical solution of a "convex shape sheet" cannot provide such a confinement but more likely evacuates the region of the equatorial sheet, above the region where the cusp is supposed to form.

A concave shape inside the current sheet corresponds to a dip of field lines; plasma accumulates easily in such stable configuration and the current sheet provides the magnetic force needed to overcome the gravity. Incidentally, concave shape features are well observed inside the equatorial sheet at time of minimum of activity. This sheet is a good prototype of streamers, see Figure 5. It seems to confirm the model (b) of Figure 4 which, in addition, is the most probable one from the point of view of the overall magnetic energy involved which should be minimal. This model reminds also the magnetosphere of a star with an accretion disk; an important difference however exists: the magnetic field here is due to the central Sun alone (with the important modification due to the field induced in the current sheet) and the equatorial current sheet is in dynamical state with outward motions.

Figure 5: Caption 5.

4 Concluding remarks on streamers

a) Solutions proposed by Pneuman and Kopp qualitatively explained the form of streamers and some distribution of plasma inside. Their main merit has been to demonstrate the importance of currents in the sheet. It is difficult in the frame of this model to predict the relative velocity of the plasma flow in the streamer, compared to the surrounding solar wind flow. This is possibly due to the absence of a relationship, besides the equation of continuity, to describe the interactions of the velocity with the magnetic field. The assumed position of a cusp, supposed to describe the actually observed phenomena, is of little use. When considering currents in the sheet flowing in a "reversed" direction like in the model shown at right in Figure 4, there is no more need to assume a cusp and the confinement is assured. Future works will have to refine these predictions. A basic requirement for models is still to confine the plasma in sheets with densities reaching values at least one order of magnitude higher than the values in the surrounding corona.

b) The problem of instabilities, starting from the tearing mode which forces currents inside the sheet to split into threads is not well understood.

Processes of reconnection are favoured; they are comparable to the magnetospheric substorms. They could occur inside streamers permanently at not too large distances from the Sun.

At large distances, there are strong indications that instabilities of the anisotropic plasma produce current threads directed along the main axis of the streamer. Electron temperatures are different along and orthogonally to the streamer axis. However, the existence of plasma flows with different velocities is an other aspect to be considered, not mentioning effects due to the turbulence coming from the magnetic viscosity. Further development of MHD models is very much needed to progress in the understanding of the physics of streamers.

c) There is also a need for improving the spatial resolution of observations to better resolve sharp edges of streamers and infer the magnitude of the magnetic field. A stereo-view of streamers would help to disentangle their 3D structure, including the twisting of the sheet which could ultimately lead to the vorticity responsable for the large scale turbulence.

Then comes the physics of the small-scale structures in streamers with a concave shape (see Figure 5). This physics is clearly non-stationary so the temporal resolution will have further to be considered, keeping an improved spatial resolution.

Only spaceborne coronagraphs of larger size can provide this progress. Eventually, measurements performed both remotely and in-situ, but very close to the Sun using a solar probe are necessary.

d) The dissipation and the interaction of the large-scale magnetic field of a star with the stellar wind takes place not only in the solar case; streamers clearly exist also in extended stellar atmospheres and the significance of this phenomenon is rather underestimated in astrophysics. It makes the case of streamers very interesting for astrophysics.

5 References

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[2] Coronal Streamers, S. Koutchmy and M. Livshits, 1992, Space Science Reviews, 61, pp. 393-417

[3] Coronal Streamers, coronal loops and coronal and solar wind composition, ESA S-P 349 (1992)

[4] Electrodynamics of Continuous Media, 2d edition, Landau, L. D., Lifshits, E. M. and Pitaevskii, L. P., Pergamon Press (1984)

6 Captions for Figures

Figure 1: Processed global coronal image. This composite shows small-scale gradients of intensities with improved visibility of faint details. The black disk of the Moon of the eclipse picture has been replaced by the SkyLab/ATM picture made in SXR (AS&E) in negative, same day and same scale. Note at the top, the polar C.H. and at lower latitudes, streamers: A- a helmet streamer with a cusp; B- a streamer with an enhanced edge (wrapped sheet); C- the stalk of a streamer far away on the back side of the Sun, composed of many fine threads. Eclipse picture of June 30,1973 and composite by the Institut d'Astrophysique de Paris, CNRS-France.

Figure 2: Large scale coronal eclipse pictures made at different phases of the activity cycle. Processed images to remove the radial gradient and subtract the background corona. North pole is at the top. The occulting disk corresponds to $1.4R_o$. Eclipse of July 20, 1972 (after a solar maximum of activity) and of Feb. 16, 1980 (during a solar maximum), observed from an aircraft by the Los Alamos Group. Pictures by courtesy of Ch. Keller (LASL, N.M., USA).

Figure 3: Electron densities deduced from the analysis of many eclipse pictures at different epochs and for different latitudes. Values for streamers and other regions are shown. The scales are chosen to permit a straightforward evaluation of the hydrostatic temperatures, see the bottom part, using the radial gradient of density variations. From S. Koutchmy, CNRS-France.

Figure 4: The set of magnetic field lines corresponding to 2 solutions of equation (4) deduced to describe the equatorial plasma sheet in equilibrium. Only the solution b/ at right gives a well confined thin sheet, with concave shape features in a dip. Drawing by courtesy of M. Molodensky, IZMIRAN- Russia.

Figure 5: Processed images of the flow in equa-

torial streamers. At left, the inner parts, above 2.2 R_o from the surface of the Sun; at right, and several hours later, the outer parts, above 4 R_o. Images are the result of the subtraction of 2 elementary images taken 1 to 2 hours apart on Jan. 23, 1997, at time of activity minimum, in W-L, using the Lasco spaceborne coronagraphs on board of the SoHO mission (ESA- NASA). Note the bright object on the large-scale image, at right, which is due to a bright planet (Jupiter in this case) crossing the field of view. Original images by courtesy of Y.-M. Wang (NRL- USA).