TIME EMBEDDING FOR THE FUTURE STEREO RECONSTRUCTIONS

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Abstract. Real and spurious topological changes seen in the coronal images can be separated when singular projection effects are eliminated by stereoscopic observations with a sufficient time continuity

Key words: solar corona, images, time, continuity

Introduction

The monocular tomography of the solar atmosphere when observed from the Earth is difficult because of large distances and small angles. Closer approach to the Sun could help, but it is not planned. Multipoint stereoscopic observations are powerful, but not always sufficient for unique solutions of 3D reconstructions. For example, the elliptic cylinder (ellipsoid) in symmetric positions against two observers can be not distinguished from the circular cylinder (sphere). Two static projections are often not sufficient for unambiguous binocular 3D reconstructions without some additional information (Vedenov, 1994) This information can be provided a priori when the objects are well known and only “labels” are searched for the recognition purposes. Unfortunately, it is not the case in the solar atmosphere. Nevertheless, the needed additional information can be obtained in many instances from the time evolution of the object under the condition of reasonable understanding of its dynamical and kinematic properties. We do not consider here the “wave sounding”. The aim of this paper is to discuss some global geometry aspects in the future 3D reconstructions from stereo-movies for CME investigations.

3D objects and 2D images (projections)

2D Images (I) are usually constructed from 3D objects (O) by the action of some projective operator ($\hat{P}$) defined on the manifold {O}. The projective transformation (mapping) is unique by definition

$$\{I\} = \hat{P}\{O\}.$$

The inverse transformation from {I} space to {O} space is not unique as a rule. The inverse operator $(\hat{P})^{-1}$ acts in the space {I}. One or more objects from {O} space correspond to each element I

$$O=\hat{P}^{-1}I.$$

The one-to-one correspondence between O and I is possible only if the continuum parametrization in {I} space is available. It is the necessary but not sufficient condition. The necessity of continuum parameters is understandable because of a more powerful manifold of the 3D space in comparison with the 2D space.

The STEREO mission purpose consists mainly in the reconstruction of {O} space. For this purpose several problems should be solved.

1) The {I} space should be reasonably defined. Practically, we need the answers to the questions: What to measure and how to do this? Let us suppose that this problem is solved in any way and we have obtained the needed information by remote sensing methods (e.g., brightness distributions, spectral characteristics, polarisation diagrams etc.). We should understand the quality of the information, its completeness, precision, error bars. Naturally, because some pre-assumptions were adopted during the formation of {I}, we should keep the reservation to check their applicability a posteriori when the intermediate or final results will be obtained and interpreted. Otherwise, pre-assumptions and hypotheses easily turn to be prejudices, which are still so common in the solar physics. To avoid this situation we need a caution and a deep understanding of the physics behind the direct operators $(\hat{P})$ and their working properties. This task is not easy and could be solved only step by step. A good library of direct transformations is useful in this respect.

2) The resolving inverse operator $(\hat{P})^{-1}$ should be properly introduced in the selected {I} space with the necessary and sufficient parametrization to reduce the unavoidable ambiguity of the decompactification. In this ideal case, we are tending to have unique solutions, i.e. correctly posed problems and stable algorithms of the deconvolution. It is a very difficult task in the case when the expected properties of the objects {O} are a priori not known. All kinds of the additional information should be incorporated in the definition of $(\hat{P})^{-1}$ to increase the number of equations to be solved in the hope to reject spurious solutions in this way. A danger exits here from both sides. The solutions are strongly not unique if the incorporated information in $(\hat{P})^{-1}$ is too scanty and the inverse problem is not completely determined. This situation is very common in coronal physics. In the opposite case, when the available information is overabundant, but not precise, we can loss the needed unique solution, because the problem can be easily made over-determined and we are facing “no solution” situations typical for “over-precision” data and models, not so uncommon in solar physics. Hence, the needed best solutions are marginally stable in this respect being at the boundary of their existence. An accurate extension of {I} space parametric dimensions and the corresponding $(\hat{P})^{-1}$ operators is very promising for a better understanding and representation attainable by the embedding of lower dimensional physical space into the higher one with new independent variables.

3) Some recognizible reference points should exist in binocular stereo-images . If such points are absent or not found, the brain (or computer) can not adequately reconstruct the 3D pattern: the correspondence between left and right elements is lost. If such points are too numerous, the relief is also lost or weak in the better case. For example, in the eroded case when left and right images are identical in the stereo-couple (the object is placed at infinity), the correspondence is perfect, but we have no information about the depth.

Hence, the binocular parallax $p = d / l$ where d is the stereo-basis, i.e. the distance between the the ‘eyes’, l is the distance to the object, should be large enough and greater than some threshold value related to the resolution limits (practically, 5-10 arcsec for the naked eye observations).

The relative binocular parallax $\delta p = d\frac{\delta l}{l^2}$, where δl is the depth difference, defines the direction and the visible distance to the object. This quantity should be small enough and less than some upper limit value $\delta p_{\max}$ determined by the nature of the object, allowing the reliable identification of the same reference point by both eyes against the background. This last quantity, $\delta p_{\max}$,is difficult to evaluate when the properties of the object are poorly known. Both local and global geometry characteristics are important in this respect for the correct interpretation. Global information is needed for the fixation of the local picture planes of both eyes. After this fixation process the recognition work takes place for the evaluation of more local details in vicinities of the selected reference points .The coherent picture is not possible when this points are lost. Practically, the limitations on the value of d appear when the broad-angle views in the left and the right eyes look very different or noisy. The recognition process fails in this case because of the lost reference points. This difficulty is most severe in the static stereoscopy ('in vitro'). The situation is more promising 'in vivo' when the object is moderately changing its attitude due to its internal dynamical processes. In that case, we have a set of consecutive stereo-couples (movies) taken from one position. When the time cadence is sufficiently high to warranty the appropriate conservation of the reference points between two snapshots, i.e. the dynamics is not too fast, we obtain the needed supplementary narrow-angle viewing information for the recognition process.

The time embedding of this kind seems to be practically very important for the future STEREO purposes. Nevertheless, even in this case, we are facing three problems of the first acquaintance, recognition and classification.

Time embedding

Stereoscopic movies open new possibilities to deconvolve 3D {O} space from parametrized 2D{I} space in the manner, which can be illustrated by several simple examples, when 3D objects are reconstructed from the usual simple movie with no additional parameters or projections.

In this case, reasonably understood dynamics or kinematics can suggest a correct solution of the 3D reconstruction problem.

1) Polar plumes. From nice SOHO/EIT movies it is clear now that plumes are linear rather than curtain-like structures (De Forest, 1998). Some of them demonstrate helical shapes (Veselovsky et al., 1999a), which can be used for the electric current estimations of ~1GA and the geometry model constructions (Fig.1, 2).

2) Coronal streamers. Their rotation with the Sun allows an approximate reconstruction of visual coronal shapes for the period of a half rotation, which could be better than an assumption of a quasi-stationary rotating pattern (Veselovsky at al., 1999b).

3) Coronal mass ejections. Dynamical motions of foot points (local rotations) for twisted loops and flux ropes add the trajectory information in depth projected on the

sphere and facilitate 3D reconstructions. Evolving 3D coronal loops are easier de-convolved from 2D projections when foot points on the sphere are seen in their perspective.

4) Dynamical shadowing effects. Moderate relative changes in the visible appearance of evolving and rotating loops allow better imagine 3D shapes when optically thin and thick parts are seen simultaneously in movies with foot points on the reference sphere. Shadowing by the solar disk also helps in some instances when the streamers, plumes are getting partially occulted.

5) Projection catastrophes are easier recognisable from real singularities in the plasma distribution when the time history is followed. Topological changes, by their definition, can be not removed by continuous transformations. Geometrical changes can be removed in this way, for example, when viewing from different aspect angles. Spurious topological changes are unstable in this respect and removable. Time evolution is a good example of a needed continuous transformation.

Coronal loops with low expansion factors

We can suggest the solution of one puzzle (Klimchuk, 2002): many coronal loops do not expand and have nearly uniform cross-sections because they are immersed not in the dipolar magnetic field assumed by Klimchuk (2002) in his model, but in the magnetic field of the horizontal linear current. Field lines of a linear current are concentric circular rings with constant magnetic field intensity. The model electrojets with currents 0.1-1.0 TA explain this puzzle and other salient features of active region loops and prominence cavities (Panasenco and Veselovsky, 2002) (Fig.3).

The prominence cavity structure in EUV lines is better resolved at the limb under the appropriate viewing angles: coronal bushes when seen perpendicular to the electrojet and rings when seen along the current axis. At the disk, the prominence cavity looks as a dark corridor with bushes at its walls. Bushes represent brighter bottom parts of magnetic loops, summits being not visible because of low contrast and luminosity.

Spurios reconnections: kinks

There is no standard definition of the term “reconnection” in the current literature (Priest, 1982). This term and its older counterpart “magnetic field annihilation” is excessive. It was not used by Faraday, Maxwell and other authors of classical works on the electrodynamics, but it can be found as a specific “argot” during last decades mostly in the papers of some authors on (space) plasma physics. Faraday introduced the field line concept and discussed the “merging” of field lines with the clear geometrical interpretation of this situation, not more. The whole building of the modern electrodynamics was constructed without using the notions of “reconnection” or “field annihilation”. Fortunately, this last term is now nearly forgotten. Usually, but not always, (see e.g., Gosling, 1999), the topological change in the field line connectivity is assumed under the term “reconnection”. This makes the use of this term somewhat ambiguous and sometimes arbitrary. For example, several “sketches of successive steps in 3-dimensional reconnection in the corona beneath a departing CME” (Gosling, 1999) are in reality couples of identical topological configurations with the same preserved connectivity, according to the standard mathematical definitions (Fig.4). The topology is completely defined and controlled by zero points and singularities. The topological change per se can be not a source of energy or lead to an enhanced dissipation of free energy. Curiously enough, but some authors write about “three dimensional reconnection points”.

What is really needed for the enhancement of the Joule dissipation, it is an increased current strength when the current geometry and material conditions are preserved or, if the total current strength is preserved, an enhanced resistivity - longer thinner current paths. In the fixed volume this practically means more complicated geometry with more developed fine structures. Similar considerations are applicable for the viscous dissipation.

Hence, we distinguish two types of energy releases: extensive and intensive. The first of them is characteristic of open physical systems driven by external forces and free energy sources situated outside the system. Solar flares and CMEs of this type are associated with larger scale reservoirs of the magnetic energy in comparison with the “local” brightest manifestations in impulsive flares. Long duration events are well known examples of bigger reservoirs. They are often accompanied by filament and prominence eruptions. The main physical cause of these events is an increase of the electric currents supplied from subphotospheric interiors.

The second type is characteristic of the closed physical system, which is getting internally unstable and leads to rapid local processes The external energy supply to the system is not essential during the characteristic “explosion” time, which is just the transition time to the new state with a less free energy. The excessive free energy is emitted as radiation or accelerated particles in impulsive flares (heat fluxes, mass fluxes, cosmic rays).

Naturally, in addition to these two extreme cases of purely “open” and “closed” evolution, intermediate cases are possible, when both factors are essential. It is especially true for the most interesting marginally stable structures, which are common in the solar atmosphere. Indeed, we often see the dynamical phenomena with preserved topological configurations and also events with drastic topological transformations. Dimensionless Trieste numbers are useful quantitative characteristics of the openness degree of physical systems in the configuration and parametric space. They are determined as dimensionless ratios of internal and linking energy, momentum and mass fluxes for a given object.

The non-linear helical kink instability of active region loops seems to be the attractive hypothesis for the explanation of twisted flare loops. According to one scenario (Linton et al., 1999), right-handed flux ropes will emerge rotated clockwise away from the usual Hale orientation, and then will rotate counter-clockwise as they evolve. The opposite will hold for tubes with left-handed twist. The entire concentrated kink would emerge into the corona and only un-kinked portions of the tube will intersect the photosphere.

Nevertheless, what we observe in numerous TRACE movies of kinked and rotating eruptive prominences and coronal loops differs from this picture (see, e.g., in Fig.5 for the February 26, 2002 twisted loops in TRACE and also in SOHO/EIT movies). Kinks (electric currents) cross the photosphere. Twisted and sheared loops often look as self-crossing structures when projected at the picture plane. Spurious cusps appear in the projections of deformed planar loops (see, e.g., Fig.4, 5 in Moses et al (1998). In reality, many wavy threads (planar, cylindrical, toroidal, more complicated and less symmetric), even if they are homogeneous along the main axis, could form caustics when mapped on the picture plane. Attempts of a mathematical classification of singularities in mappings can be found in the literature (Arnold et al., 1982). The same caution can be expressed regarding "sigmoids". The detailed analysis of them with a higher resolution often shows individual loops and two differently inclined loop systems tracing different field lines and not just a tube of S-shaped field lines as often assumed in the literature. The middle of bright coronal "S" is often interrupted by the dark space corresponding to the gaps between these two bright coronal loop systems individually rooted with their legs in the photosphere. We should distinct between these topologically different situations for the correct interpretation of images with real S-shaped coronal field lines or projection effects

Many dynamical structures seen in the solar atmosphere preserve their overall (or local) topology (see e.g. Uchida, 2000), but appear as changing their connectivity due to projection catastrophes and singularities which have nothing to do with real topological changes and difficult to deconvolve from static images, but easier recognisable in movies. Some of ambiguities in 3D reconstructions can be removed in this way. It is especially true, when we have an additional physical information, which can be included in the analysis a priori for the test of different possible (often not unique) solutions.

This can be demonstrated effectively by STEREO on the examples of coronal electrojets with their characteristic arcades seen already in EUV SOHO/EIT images.

Discussion

Here we comment on several popular terminological concepts, which could be of some interest to the three-dimensional aspects and the physics related to the main STEREO aims.

1) "Solar source of interplanetary magnetic fields" (Wilcox and Ness, 1969). The magnetic field has no sources by definition because it has no divergence.

2) "As in many other flare models, we consider magnetic reconnection as the source of solar flare energy" (Voitenko and Goossens, 1999). Here "reconnection" substitutes "energy dissipation".

3) "A genetic magnetic field has the important property of always obeying an ideal Ohm's law locally" (Boozer, 1999). The pre-assumption of the ideal conductivity approximation turned to be prejudice because "always". The correct statement should be "not always".

4) "The essential point is that the electric current flows in the moving frame of reference of the fluid or plasma, in which there is no electric field, and therefore no powerful inductive effects" (Parker, 2001). The case of no dissipation is assumed. It is only the crude approximation (see previous point 3), but not the general rule of nature as stated. Contrary to this statement, inductive electric fields in the solar atmosphere are playing very important role. Plasma often easily drifts in the crossed inductive E fields and time dependent B fields (see movies of dynamical loops in the solar corona).

5) "It is easy to show from Ampere law that the net current flowing along an isolated fibril is zero and hence that the net longitudinal current carried by a distribution of fibrils is zero" (Parker, 1996). If you assume isolator, you obtain isolator with zero

currents. If you assume zero, you obtain zero. We read further: "Insofar it is correct, it follows that there are no mean longitudinal currents anywhere in the convective zone". It is not correct because the conductivity is not zero. The general conclusion about "actual, vanishing mean current" is physically wrong and based on the prejudice of solar interiors as an isolator.

6) "The X-ray corona of the Sun consists of tenuous wisps of hot gas enclosed in strong (10^2 G) bipolar magnetic fields" (Parker, 1988). Not only. The quantitative measure is not known and need observations with better resolutions.

STEREO can help to overcome some of existing prejudices, which are based on pre-assumptions of the ideal plasma and simple geometry. We expect to see manifestations of non-local magnetic couplings, electric currents and charges, mass motions along and across the magnetic fields, energy and momentum transports in static and dynamics structures.

Figure captions

(Figures from the original poster presentation are not shown and only listed below)

Fig.1. Helical polar plumes

Fig.2. Geometry of polar plumes

Fig.3. Coronal electrojet

Fig.4. Geometry changes associated and not associated with topological transitions

Fig.5. Spurious reconnections. Side views of non-planar loops in their time evolution (Trace, Yohkoh)

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Conclusions

STEREO observations could resolve real topological changes, which obviously happen in the solar atmosphere and in the heliosphere. Stereoscopic data can be used to overcome some of projection effects when caustics are formed in the coronal images. We demonstrate that twisted loops in many instances can be misinterpreted as "reconnection" events because of the projection "catastrophes" in the images. The formation of spurious singularities like cusps, folds, islands, detached or disconnected elements is often observed in coronal images. Stereoscopic movies are promising for the reducing the remaining binocular reconstruction ambiguities. The likelihood of the correct interpretation of the transparent dynamical object is generally higher than for the static object of the same complexity because of the using of the "forth co-ordinate" and the "time embedding". Examples were presented when partial and restricted reconstruction is attainable with TRACE movies for the 3D loop systems when the condition of their moderate dynamics in active regions is fulfilled. The reasonable time cadence of the order of 1 min or even better and the continuity of observations is necessary in this case for the 3D reconstruction of the prominence eruptions and eruptive flares. Long duration coronal events associated with CMEs probably can be reconstructed with a lower cadence.

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