The Case for Flux Submergence

I. Theory

General considerations

Parker, E. N. (1984), Magnetic buoyancy and the escape of magnetic fields from stars, *ApJ* **281**, 839–845,

> Propses the net azimuthal flux from one phase of cycle is sloughed away by a series of reconnections of neighboring loops one to the next. "The essential point is that the escape of net azimuthal flux through the surface of the star necessarily involves the reconnection of flux above the surface of the star as the only means of freeing the field from its burden of dense gas.".

Vainshtein, S. I. and Rosner, R. (1991), On turbulent diffusivity of magnetic fields and the loss of magnetic flux from stars, *ApJ* **376**, 199–203,

> Expansion of ideas of Parker (1987) about azimuthal flux loss through reconnection. Also presents estimates of turbulent diffusion rates. Show these to be insufficient to present alternative.

Parker, E. N. (1987), The dynamical oscillation and propulsion of magnetic fields in the convective zone of a star. I. General considerations, *ApJ* **312**, 868–879,

> Proposes that an activity nest is a thermal relaxation oscillation. Motivates idea by showing the mean azimuthal field strength required to save up all separate active regions below surface prior to eruption is unacceptably large (30,000 kG). "...intermittently opens and closes allowing occasional upsurges of fluid and field." "...after a few days...the downdraft [pulls] the field back into the sun.".

Negative buoyancy

Vainshtein, S. I. and Levy, E. H. (1991), Dynamical behavior of strong magnetic fields in the solar convection zone., **135**, 261–274,

> Discusses the value of buoyant force in flux tube. Shows that for most conditions very small temperature deficit cancels out buoyancy of field. This deficit is natural consequence of inhibition of turbulent heat transport. "...after penetrating photosphere [the flux tube] rapidly loses heat...enough to overcome buoyancy.".

D'Silva, S. (1995), Flux retraction and recycling: nagative buoyancy induced oscillations as an alternative to Parker's thermal relaxation oscillations, *ApJ* **448**, 459–469,

> Finds nonlinear equations for time evolution of azimuthal flux tube. These expand the ideas of Vainshtein and Levy (1991). Finds numerical solutions which rise and fall.

II. Observation

Whole Active region flux

> No observations of either submergence or expulsion of whole AR flux – all ARs show evidence of only fragmentation.

Small flux regions – submergence

Rabin, D., Moore, R., and Hagyard, M. J. (1984), A case for submergence of magnetic flux in a solar active region, *ApJ* **287**, 404–411,

> Using MSFC vector magnetograms, $H\alpha$ and $Ly\alpha$ images it has been observed that a part of NOAA AR 2372 (4×10^{20} Mx concentrated in an area 30 arc sec) disappeared overnight. They estimate that diffusion and fluid flow could dissipate about 10% of this missing flux, only. Because of low activity and low magnetic shear they also ruled out reconnection as a primary reason of flux disappearance. There is no indication of missing flux in $H\alpha$ and $Ly\alpha$. Conclusion is that flux submerged.

Martin, S. F., Livi, S. H. B., and Wang, J. (1985), The cancellation of magnetic flux. II. In a decaying active region, *Australian Journal of Physics* **38**, 929–959,

> (Frequently cited, but not found in our library).

Zirin, H. (1985), The rise and fall of sunspot group 18962: a case of magnetic submergence, *ApJ* **291**, 858–859,

> Using chromospheric images ($H\alpha$) and Big Bear Vector Magnetograms he observed emergence and submergence of small bipolar active region. First day, EFR showed behavior typical for emerging flux: gradual development of the arch filaments, downflows near edges of the filaments, pores in the photosphere. Next day, however, magnetic hills stopped their moving apart and started move back (toward to each other). Arch filaments were decreasing in length during this period. Finally, active region disappeared.

Wallenhorst, S. G. and Topka, K. P. (1982), On the disappearance of a small sunspot group, *Solar Phys.* **81**, 33,

> Used longitudinal magnetograms in study small active region. Did not observed spreading or diffusion of outer boundary active region (but (?) discuss fragmentation of the dominant spot). Discuss submergence as one of possible interpretations. (However, they do not have $H\alpha$ or coronal observations, so it is not convincing result to me).

Small flux regions – emergence

Lites, B. W., Low, B. C., Martinez-Pillet, V., Seagraves, P., and Skumanich, A. (1995), The possible ascent of a closed magnetic system through the photosphere, *ApJ* **446**, 877,

> Used ASP vector magnetograms, SXT-images, $H\alpha$ and longitudinal magnetograms from La Palma. Observed evolution of delta-spot in AR (The mature sunspot of this AR was unchangeable (my impression) and showed MMF). Magnetograms shows that magnetic field was concave upward. $H\alpha$ filaments were parallel to the neutral line at the beginning and rotate gradually to became perpendicular to the neutral line through the observational period (Possible indication of rising sheared loop system). SXT source persisted well after the delta-spot disappeared in the photosphere. They also show magnetostatic model describing most of observing features.

Smaller scales

Observational evidence is weak.

MMF is cancellation of flux, but where it is going (?)

There are several papers on moving magnetic features (MMF) describing them as real motions of the two footpoints of same flux tube eg, Nye, A.H., Thomas, J., H., Cram, L.E., 1984, ApJ, 285, 381. There is two types of MMF. First type: one polarity footpont is moving from sunspot toward opposite polarity outside spot (sometimes, they move toward each other). After they reach each other, they disappear. Second kind: both polarities move together, one after other, disappear outside moat surrounding sunspot. To me, MMF are indirect evidence of submergence. There is no coronal and (sometimes) *very* weak (?) chromospheric counterparts of MMF, so they are low atmosphere features. Apart from that, since they are moving "disturbances" on magnetic flux tubes, should we expect coronal indication of related energy transport?

Interplanetary magnetic field

Smith, C. W. and Bieber, J. (1991), Overwinding of the IMF, *ApJ* **370**, 435,

They studied difference between average observed interplanetary magnetic field and predicted by Parker model. So, they found that observed IMF is more spiraling than model's and explain that by additional toroidal flux escaping the Sun.

Bieber, J. and Rust, D. (1995), The escape of Magnetic Flux from the Sun, *ApJ* **453**, 911–918,

They computed total magnetic flux (IMF) measured at 1 AU and found that it is roughly equal to the total observed photospheric magnetic flux (during solar cycle). Compare found total flux at 1 AU with different numbers of photospheric flux (with or without ephemeral active regions) they conclude that 20%–100% of all emerging flux need to be removed from the Sun. A model for removing toroidal flux is similar to the Vanshtein & Rosner (1991) description. However, I think, once disconnected from the Sun their toroids should move up or down (parallel to the solar rotation's axis, not radially from the Sun).