EPSC Abstracts
Vol. 12, EPSC2018-940, 2018
European Planetary Science Congress 2018

Modelling Flux Ropes in the Ionosphere of Titan

C J Martin (1), C S Arridge (1), S V Badman(1), L C Ray(1), C T Russell (2), H Y Wei (2) and M K Dougherty (3)
(1) Department of Physics, Lancaster University, Bailrigg, Lancaster, UK (c.martin1@lancaster.ac.uk)

(2) IGPP, University of California LA, USA

(3) Blackett Laboratory, Imperial College, London UK

Abstract

Titan is Saturn's largest and most compelling moon. Its unique interaction with Saturn's magnetic field makes it a hotbed for the study of dynamic features such as flux ropes (bundles of twisted magnetic field). Titan itself has no intrinsic magnetic field, but as Saturn's magnetosphere rotates it builds up a draped magnetic field, very similar to Venus' interaction with the solar wind, which is `caught-up' in Titan's dense ionosphere. We use Cassini magnetometer data to detect flux ropes, and use a number of force-free and non-force-free models to examine the differences and similarities between these flux ropes and flux ropes found at other planetary ionospheres. We comment on how the presence of flux ropes in Titan's ionosphere are effected by the changing magnetic interaction we see at Titan. We also infer how the flux ropes may initiate and develop using Bayesian inference to show the different properties of each flux rope.

1. Introduction

Flux ropes are ubiquitous throughout the solar system and are bundles of magnetic field that have a strong axially aligned field at the center which becomes increasingly tangential with radius. Saturn's magnetic field is stretched outward at the equator due to centrifugal stresses [4] and flaps up and down with a number of periodicities [5,6]. As Titan orbits at Saturn's rotational equator just inside the magnetopause we find that Titan is exposed to a number of varying magnetic environments and as Titan has no intrinsic magnetic field of its own, but a very thick ionosphere and atmosphere, we find that Saturn's field is 'captured' by the ionosphere [7]. We use Cassini magnetometer [1] data to detect flux ropes in Titan's ionosphere by finding large peaks in magnetic field magnitude and use variance analysis to determine if the field shows a flux rope-like structure

2. Models

We test a number of models to determine the properties of the flux ropes, such as the radii, axial magnetic field (as we will rarely sample the center of the flux ropes) and the flux content of each one. The first model we will investigate is the force-free model [2]. This model is based upon the Bessel function solutions in cylindrical co-ordinates. The second model we will discuss in depth is the non-force-free Nieves-Chinchilla [3] model. This model does not assume that the JxB force in the flux rope is zero, and hence we fit for a polynomial expansion of the currents in the flux rope. Both models also assume that the flux rope is not bent and has a perfectly circular cross-section, we will further discuss the implications of a bending flux rope model as well as flux ropes with an elliptical cross section.

3. Results

We find that, through use of the two models discussed above, that the 85 flux ropes found at Titan are more suitably fitted to a non-force-free model than the force-free model. We also find that using a bent flux rope model will also effect the parameters that are given by the fitting and hence we show that the models may not give accurate values of radius and axial magnetic field if the flux rope is suspected to be in a bent or twisted configuration. Figure 1 shows a comparison of values found from both models, the distributions are built using kernel smoothing where each value has a mean (its value) and a standard deviation (its uncertainty) which makes a normal distribution peak. All of these normal distributions are added together to build the probability distribution shown. Further to this we will investigate all the properties of the flux ropes using Bayesian inference to show the interdependence and improved error analysis of the parameters fitted to both models. The section below shows a typical example where the non-force-free model shows an improved fit (figure 2).

4. Figures

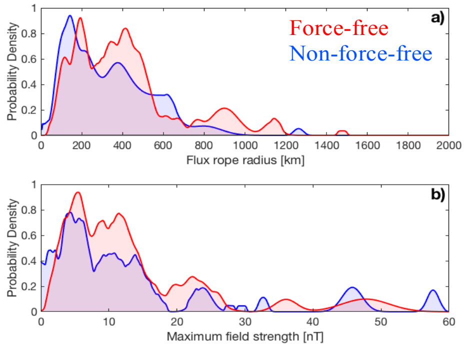

Figure 1: The comparison of values of radii (a) and axial field strength (b) of the force-free (red) and non-force-free (blue) models.

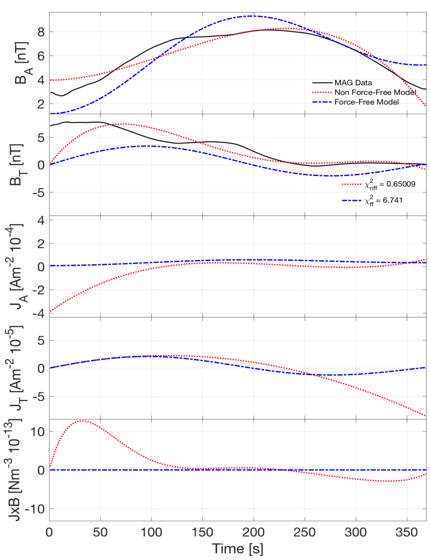

Figure 2: Figure shows a comparison between a non-force-free (red) model fit to a force-free (blue) model fit to data (black). The top two panels show magnetic field in the Axial and tangential directions and the bottom three show the currents expected from both models and the JxB force. Note how the JxB force of the force-free model is near zero.

5. Summary and Conclusions

We have discussed the highly dynamic and variable environments that Titan can be exposed to, and in these environments we find changing numbers of flux ropes. We hope to link the magnetic environment with the formation and development of flux ropes using Bayesian inference in the near future and show that Titan is an ideal environment for creating flux ropes, but not sustaining them. The use of both models discussed already show that the majority of flux ropes cannot be considered force-free and hence can be classed as 'non-matured' flux ropes.

References

[1] Dougherty, M. K., S. Kellock, D. J. Southwood, A. Balogh, E. J. Smith, B. T. Tsurutani, B. Gerlach et al. "The Cassini magnetic field investigation." In *The Cassini-Huygens mission*, pp. 331-383. Springer, Dordrecht, 2004.

[2] Lepping, R.P., Jones, J.A. and Burlaga,L.F.: Magnetic field structure of interplanetary magnetic clouds at 1 AU in Journal of Geophysical Research. Vol. 95 A8 (1990)

[3] Nieves-Chinchilla, Teresa, M. G. Linton, Miguel A. Hidalgo, Angelos Vourlidas, Neel P. Savani, Adam Szabo, Charlie Farrugia, and Wenyuan Yu. "A circular-cylindrical flux-rope analytical model for magnetic clouds." *The Astrophysical Journal* 823, no. 1 (2016): 27.

[4] Arridge, C. S., C. T. Russell, K. K. Khurana, N. Achilleos, S. W. H. Cowley, M. K. Dougherty, D. J. Southwood, and E. J. Bunce. "Saturn's magnetodisc current sheet." JGR: Space Physics 113, no. A4 (2008).

[5] Provan, G., David Jeremy Andrews, Chris S. Arridge, Andrew J. Coates, S. W. H. Cowley, G. Cox, M. K. Dougherty, and C. M. Jackman. "Dual periodicities in planetary-period magnetic field oscillations in Saturn's tail." Journal of Geophysical Research: Space Physics 117, no. A1 (2012).

[6] Arridge, Chris S., N. André, K. K. Khurana, C. T. Russell, S. W. H. Cowley, G. Provan, D. J. Andrews et al. "Periodic motion of Saturn's nightside plasma sheet." *Journal of Geophysical Research: Space Physics* 116, no. A11 (2011).

[7] Bertucci, C., N. Achilleos, M. K. Dougherty, R. Modolo, A. J. Coates, K. Szego, A. Masters et al. "The magnetic memory of Titan's ionized atmosphere." Science 321, no. 5895 (2008): 1475-1478.