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The auroras of Earth: illuminating the engine of magnetospheric dynamics

S. E. Milan
University of Leicester, Department of Physics and Astronomy, Leicester LE1 7RH, UK (steve.milan@ion.le.ac.uk)

Abstract

The auroral morphology and dynamics at Earth are primarily driven by the interaction of the solar wind with the terrestrial magnetosphere, and as such, observations of the auroras provide a powerful diagnostic of the coupling between the solar wind, magnetosphere, ionosphere, and atmosphere. Changes in the size of the polar cap, the dim region encircled by the auroral oval, quantifies variations in the open magnetic flux content of the magnetosphere, effected through magnetic reconnection occurring at the magnetopause and in the magnetotail. This reconnection drives the Dungey cycle of plasma and magnetic flux, the engine of magnetospheric dynamics. Features within the auroras reveal the working parts of this engine, such as the cusp spot, flux transfer events, the substorm auroral bulge, auroral streamers, and transpolar arcs.

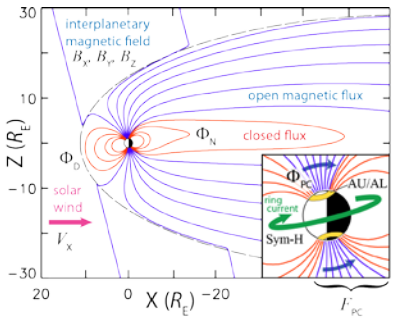

Figure 1: The locations of the auroral ovals reflect the structure of the magnetosphere, determined by the coupling with the solar wind and interplanetary magnetic field. Increasing open flux leads to expanded polar caps, low latitude auroras, and an inflated magnetotail [8].

1. Large-scale auroral morphology

Magnetospheric structure and dynamics arise through the coupling of the interplanetary magnetic field (IMF) with the terrestrial dipole by magnetic reconnection at the magnetopause. A proportion of the Earth's magnetic field becomes open, allowing ingress of solar wind plasma, and forming the magnetotail lobes (Figure 1). The location of the auroral ovals reflect the proportion of the magnetosphere that is open; as reconnection proceeds, the auroras move to lower latitudes, indicating an inflation of the magnetotail and an increase in the solar wind stress on the tail magnetopause.

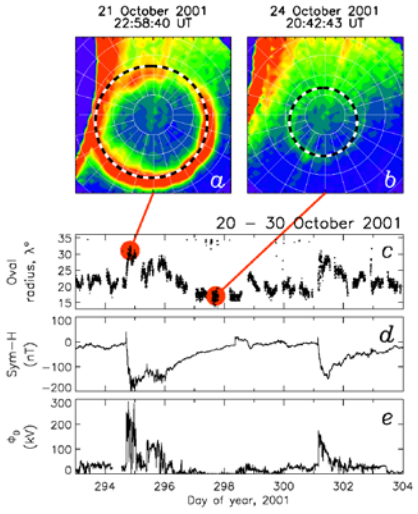

Figure 2: Auroral observations from the IMAGE FUV instrument over the course of two geomagnetic storms (depressions in Sym-H) show long timescale increases in the size of the polar cap (the dim region inside the auroral oval, the footprint of open magnetic flux), giving rise to low latitude auroras. Short time-scale (few-hour) variations in polar cap size are associated with individual substorms, the heartbeats of the magnetosphere [7].

Eventually, the external stress induces magnetic reconnection in the tail neutral sheet, triggering a magnetospheric substorm, accompanied by energy deposition in the ionosphere. Open flux is closed and the auroras move poleward again. Addition of open flux at the dayside and its subsequent release on the

nightside are the drivers of a progressive circulation of magnetic flux, magnetospheric convection, and corresponding motions of the ionosphere, antisunward flow over the poles and sunward flow at lower latitudes. The expanding/contracting polar cap paradigm (ECPC) provides a coherent framework in which to understand magnetospheric structure and dynamics [6]. Auroral imagery reveals the changes in the interconnection between the magnetosphere and the interplanetary medium on geomagnetic storm and substorm time-scales (Figure 2).

2. Small-scale auroral features

Small-scale features in the auroras are often linked to the action of the reconnection process itself. During periods of southwards IMF, "flux transfer events" – episodic bursts of subsolar magnetopause reconnection – are seen as series of dayside poleward moving auroral forms [4,9]. On the nightside, the formation of a substorm auroral bulge indicates the onset of magnetic reconnection in the magnetotail. North-south aligned auroral features ("streamers") within the bulge are thought to be associated with individual, spatially-limited bursts of reconnection and the Earthward propagation of newly-closed flux tubes [2].

During northward IMF, magnetic reconnection occurs at high latitudes, tailwards of the cusp openings, with the open field lines of the lobes. Under suitable conditions a "cusp spot" marks the ionospheric projection of the reconnection site within the polar cap [3] (Figure 3). The location of this spot changes with the east-west orientation of the IMF, reflecting the location of the reconnection site on the magnetopause.

When the IMF remains northwards for prolonged periods the magnetosphere can develop magnetotail lobes bifurcated by a tongue of closed magnetic flux, reflected in the auroral configuration by a sun-aligned auroral feature that extends across the polar cap from nightside to dayside ("transpolar arcs" or "theta auroras") [1]. The formation of these has been linked to reconnection occurring in a twisted magnetotail and subsequent motion to the action of lobe reconnection [5].

Acknowledgements

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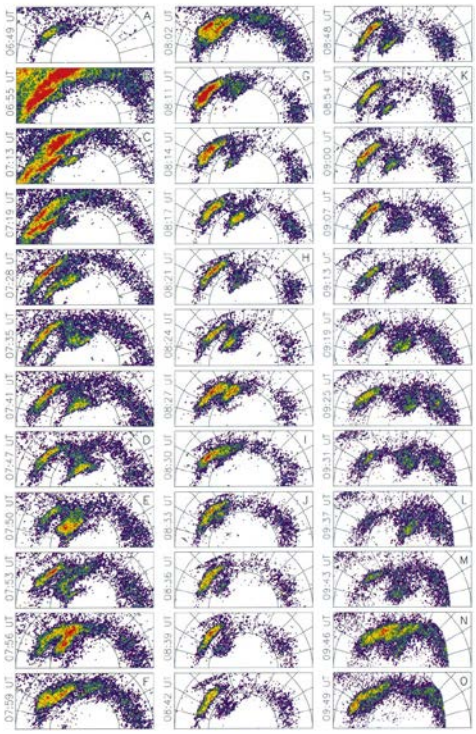

Figure 3: A sequence of auroral images collected by the Polar UVI instrument on 26 August 1998 showing the dayside auroral oval and the presence of a "cusp spot" in the open polar cap, the footprint of the lobe reconnection site. The pre-/post-noon location of the spot changes with IMF orientation [3].

References

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