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Particle acceleration at 3D magnetic reconnection sites

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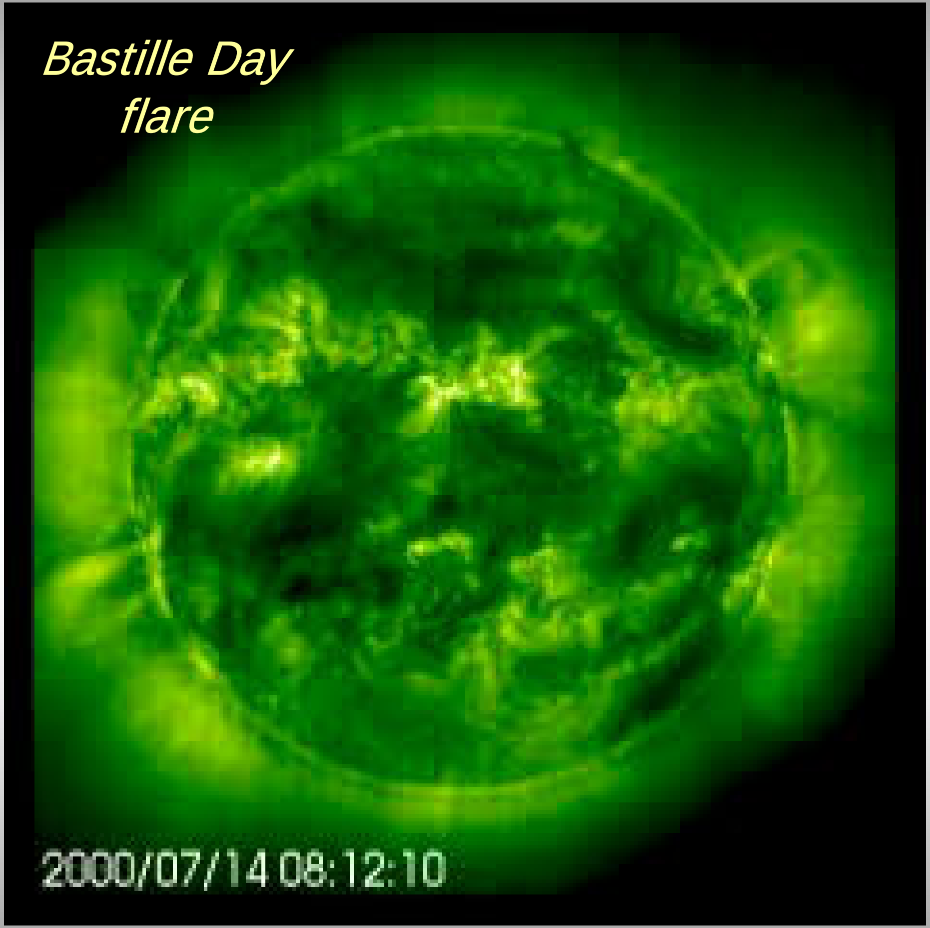
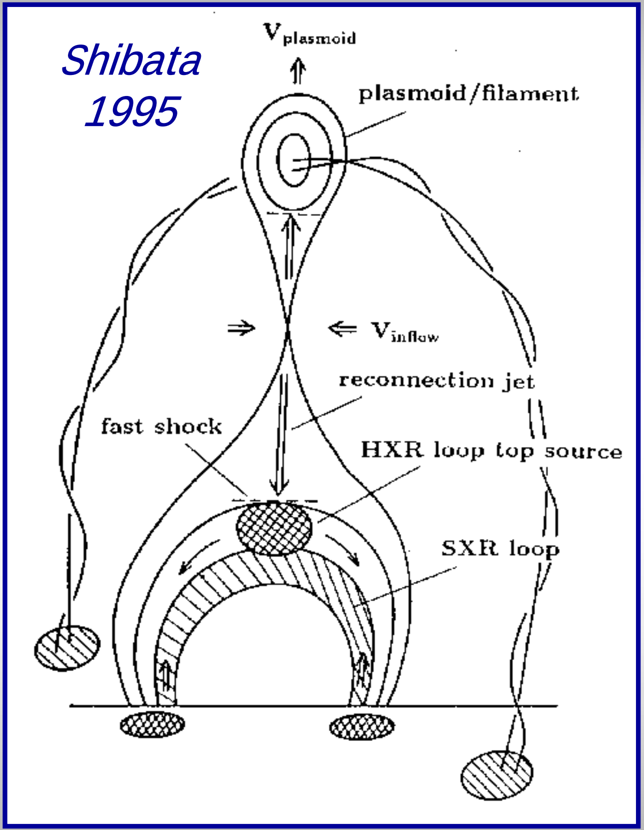
Solar flares

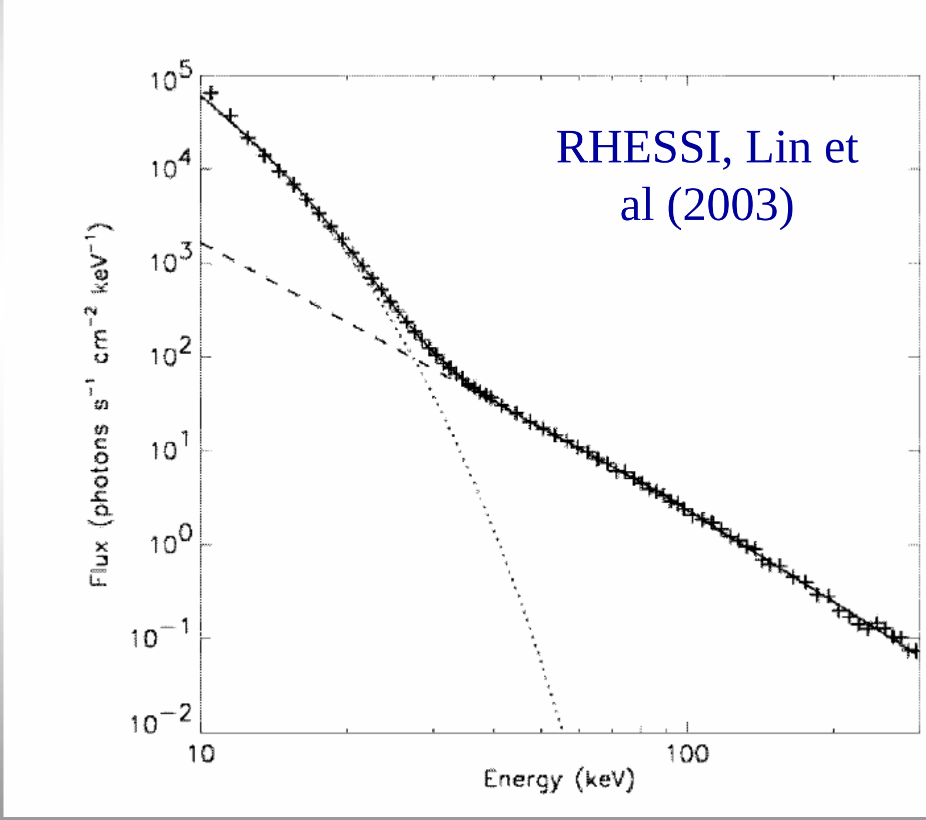




•Release of stored magnetic energy by magnetic reconnection

Particle acceleration in solar flares

- Flares produce large numbers of high energy (non thermal) protons and electrons as well as heating plasma
- Magnetic reconnection is believed to be fundamental process of energy release in solar flares
- Are direct electric fields associated with reconnection responsible for generating high energy particles?
- Similar processes may accelerate particles in other contexts – Earth's magnetosphere, extragalactic jets, pulsars etc



Test particle approach to modelling particle acceleration

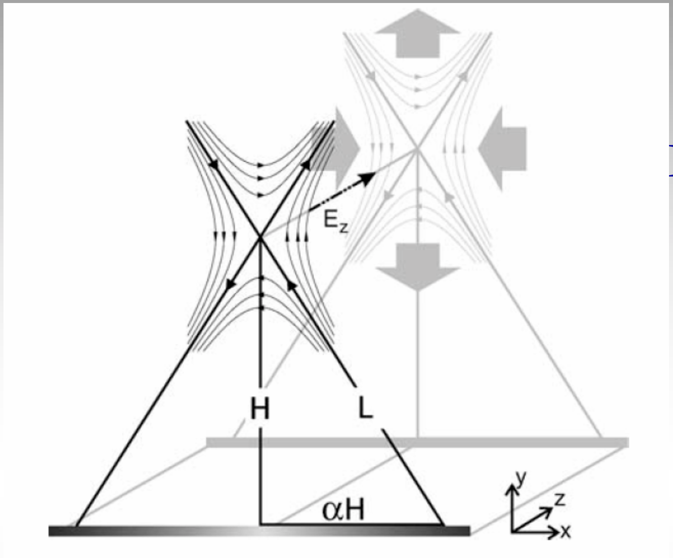
- Take magnetic and electric field configuration representative of reconnection
- Neglect the fields generated by the test particles and (usually) neglect collisions of test particles with the background plasma – no energy losses
- Integrate equations of motion numerically
- We undertake test particle simulations in 3D fields

$$\frac{d\mathbf{x}}{dt} = \frac{\mathbf{p}}{m\gamma}$$

$$\frac{d\mathbf{p}}{dt} = q\left(\mathbf{E} + \frac{1}{c}\frac{\mathbf{p}}{m\gamma} \times \mathbf{B}\right)$$

2D test particle models

- X-point or current sheet configuration
- Invariance of all quantities in the 'z' direction - with or without "guide field" B_z
- Many studies e.g. Vekstein and Browning (1997), Deeg et al (1990), Browning & Vekstein (2001), Zharkova & Gordovsky (2005), Hamilton et al (2003).. etc



Hannah & Fletcher, 2006

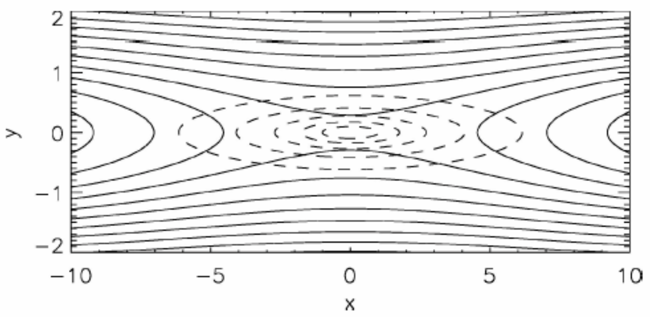
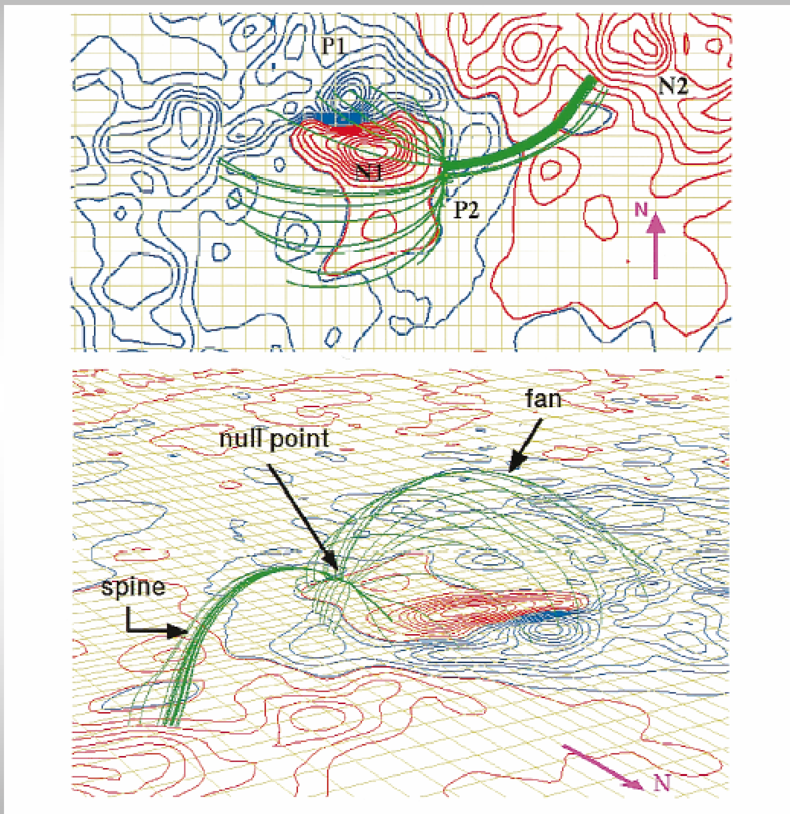


Figure 1. An example of the field configuration used in this paper (using $L = 10$). Note that for graphical reasons the configuration is not shown with the correct aspect ratio, so that it is actually a lot more elongated in the x-direction than shown here. The *solid lines* are projections of magnetic field lines onto the $x-y$ plane (contours of the flux function A). The non-ideal region in which a field-aligned component of the electric field exists is outlined by the *dashed contours*.

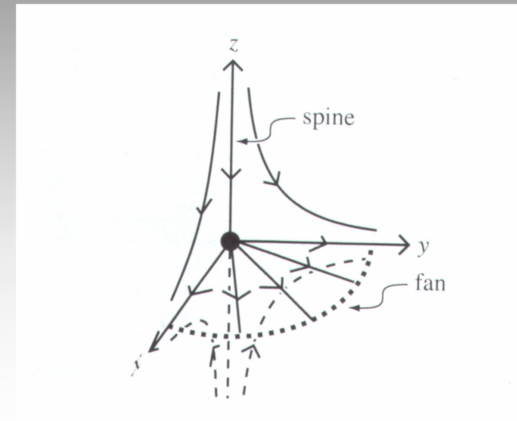
Wood & Neukirch, 2005

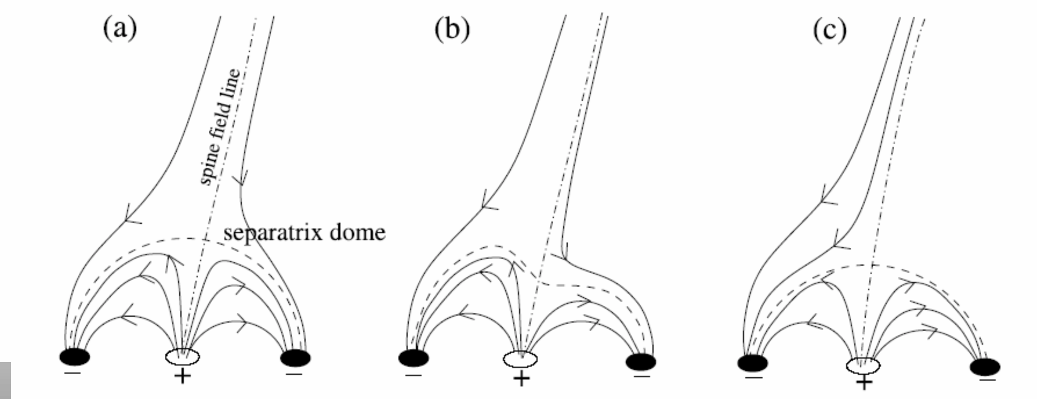
3D null points in flares



Aulanier et al (2000)

3D null points

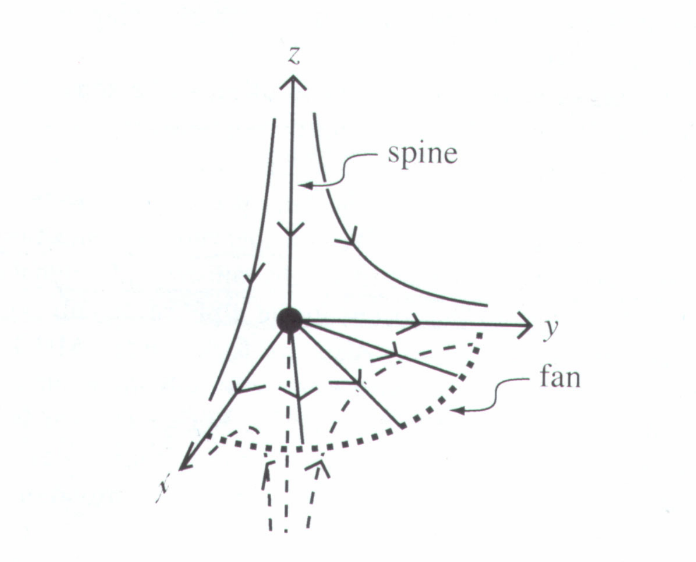




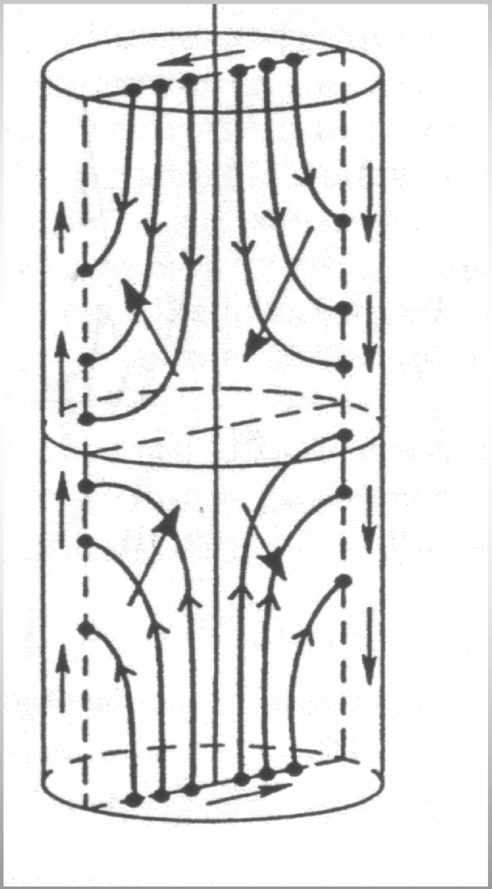
Fletcher et al (2001)

Spine and fan reconnection

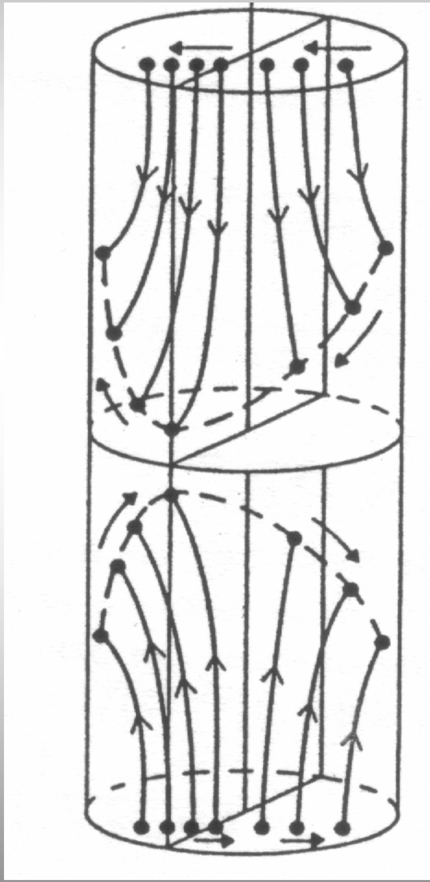
Priest and Titov (1996)



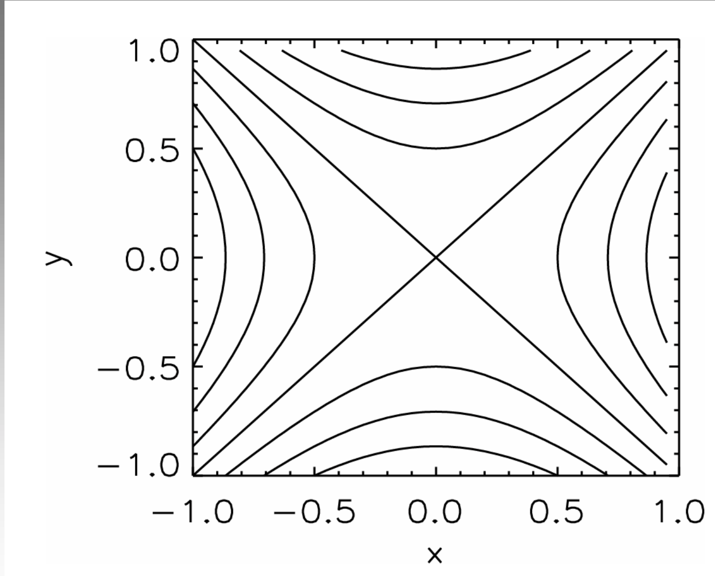
$$\mathbf{B} = B_0 \frac{R}{L} \mathbf{e}_R - 2 B_0 \frac{z}{L} \mathbf{e}_z$$

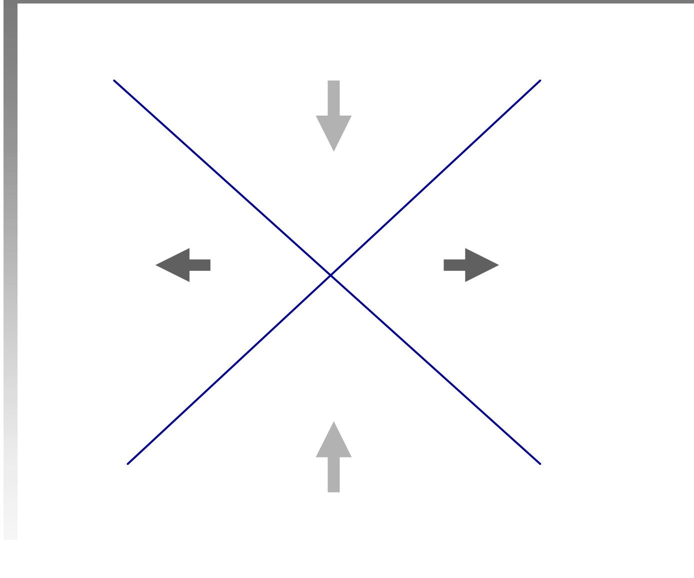


Spine

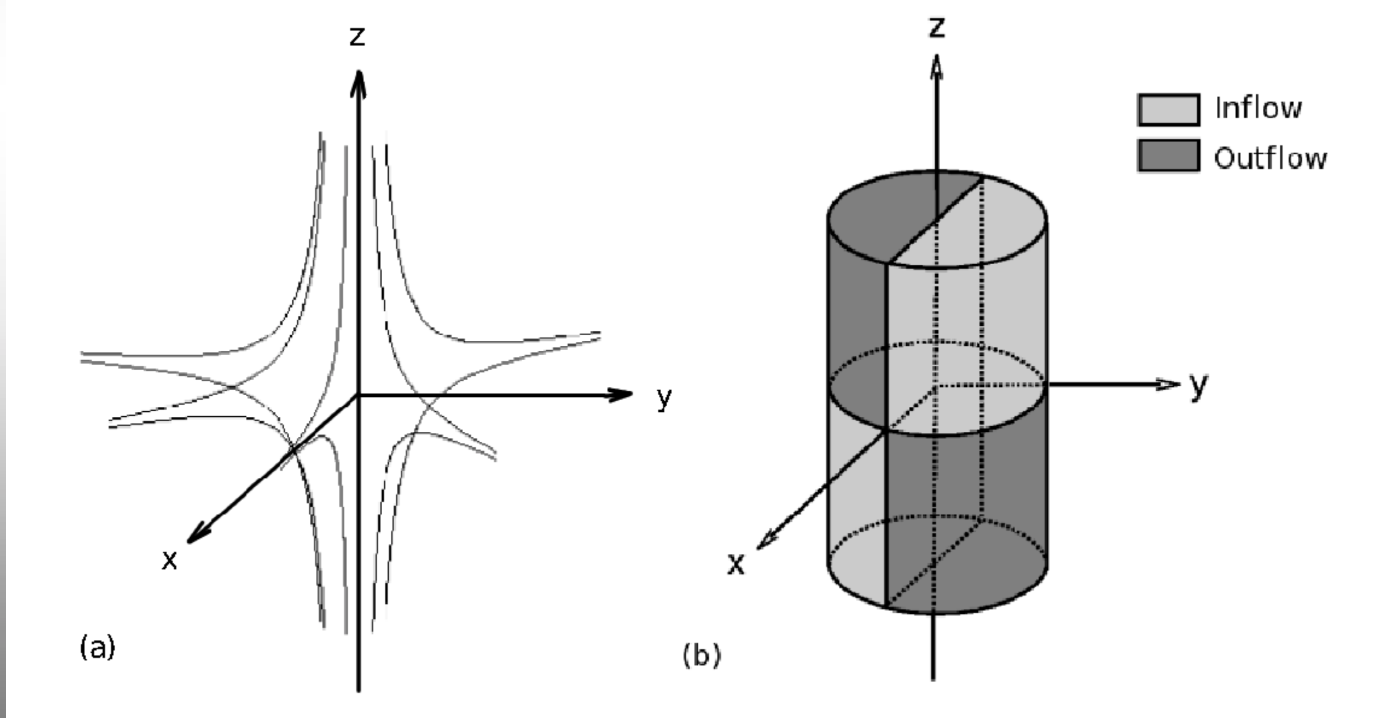


Fan





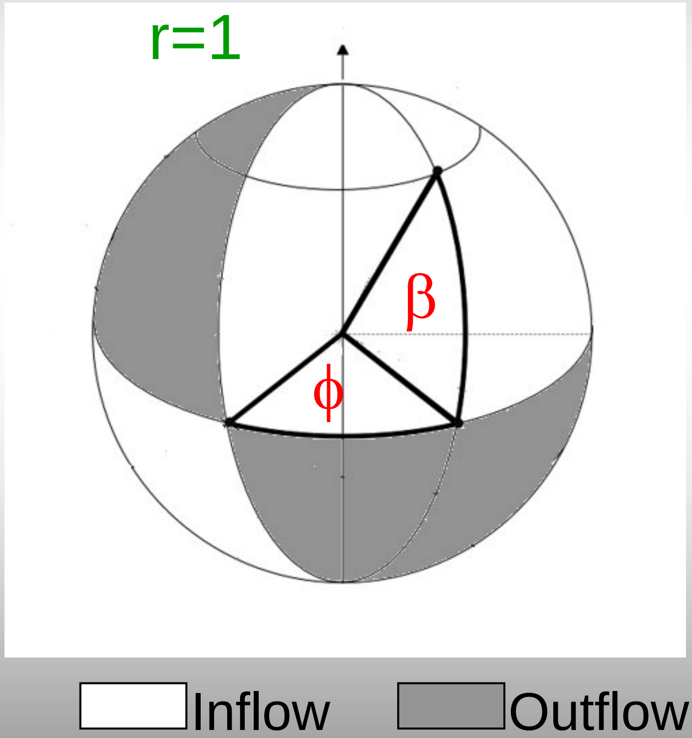
2D



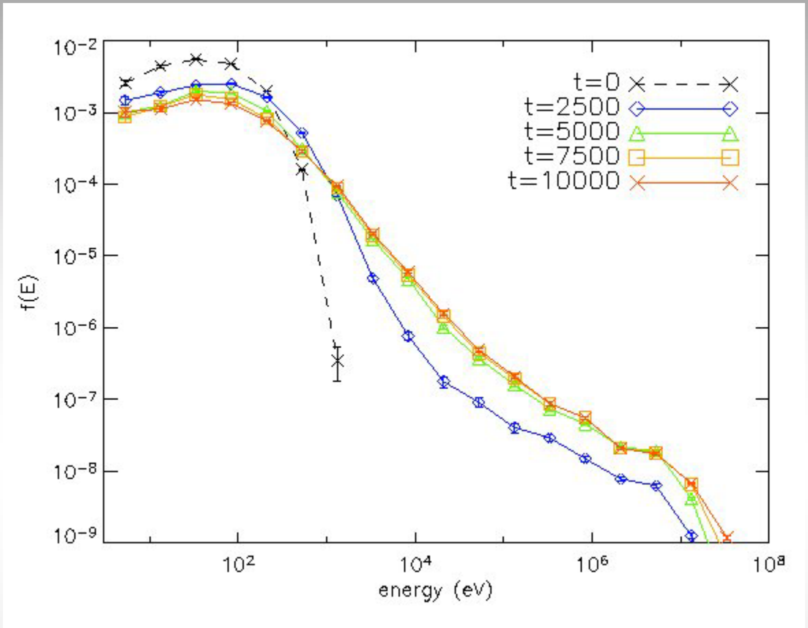
3D (spine)

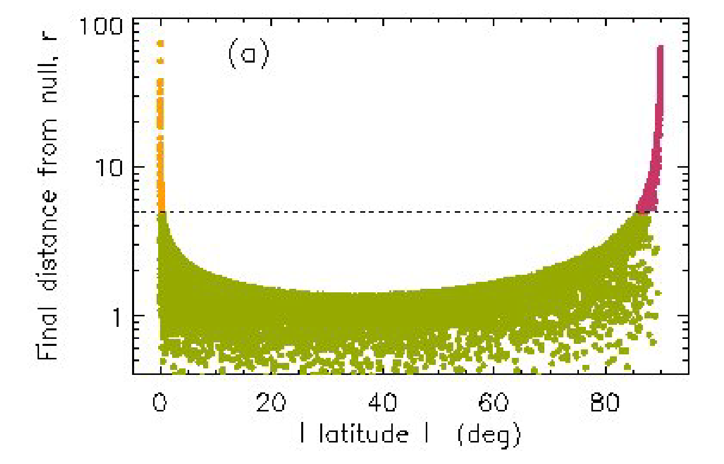
Acceleration of test particles

- Consider only outer "ideal" region - acceleration due to non-uniform **E** X**B** drift
- Particles become unmagnetised (large Larmor radii) near spine/fan
- Ignore (for now) acceleration due to $E_{//}$ in resistive region (current sheet/filament)
- Inject ensemble of particles on a sphere of normalised radius r=1
- 10,000 protons. Start in inflow regions, with uniform random positions. Velocities from Maxwellian (T = 1 million K)



Results – see poster!





- Calculate energy spectra of particles in spine and fan reconnection
- Also analyse spatial distribution and pitch angles of particles
- Energy gain depends strongly on entry location – investigate individual particle trajectories
- In spine reconnection, a jet of high energy particles escapes along the spine – also trapped high energy particles are generated
- Acceleration is less effective in fan reconnection
- Scaling with reconnection parameters is considered