Modelling Aurora Borealis through Lorentz Force

A Comparison of Aurora and STEVE

Brean Prefontaine and Laura Wood

Background

How do the auroras form?

- Solar wind → Earth's magnetic field ⇒ generates electrical currents in the magnetosphere
- Accelerate charged particles into upper atmosphere, which collide with various gases
- Randomly transfer energy to atmospheric atoms and release energy through fluorescent emission

Aurora Borealis

- **Usually green, yellow, and red**
- **Can also be pink, violet, and blue**
- **Curtain shaped**
- **60-80º MLAT (magnetic latitude)**
- **Formed by charged particles in solar wind that interact with the earth's magnetic field**
- **Last about 10 mins to all night**
- **Highest activity in the northern hemisphere (borealis) is during spring because of solar magnetostorms**
- **Activity happens in 22 year cycles**
- **About 10 degrees latitude high**

STEVE

- **Purple in color**
- **Sometimes seen with green aspects**
- **Typically a vertical arc**
- **Below 60º MLAT**
- **Formed by subauroral ion drifts that occur during substorms**
- **Last about 20 mins to an hour**
- **Seasonal: not observed in winter (October - February)**
- **About 0.5 latitude wide**

Comparison of key features of the aurora borealis and of STEVE (Strong Thermal Emission Velocity Enhancement)

- STEVE is a backronym given to a special kind of aurora that was recently discovered by scientists
- STEVE is narrower and more vertical than typically studied auroras and usually purple, while auroras can be many other colors
  - The colors of auroras are dependent on interactions of specific gases

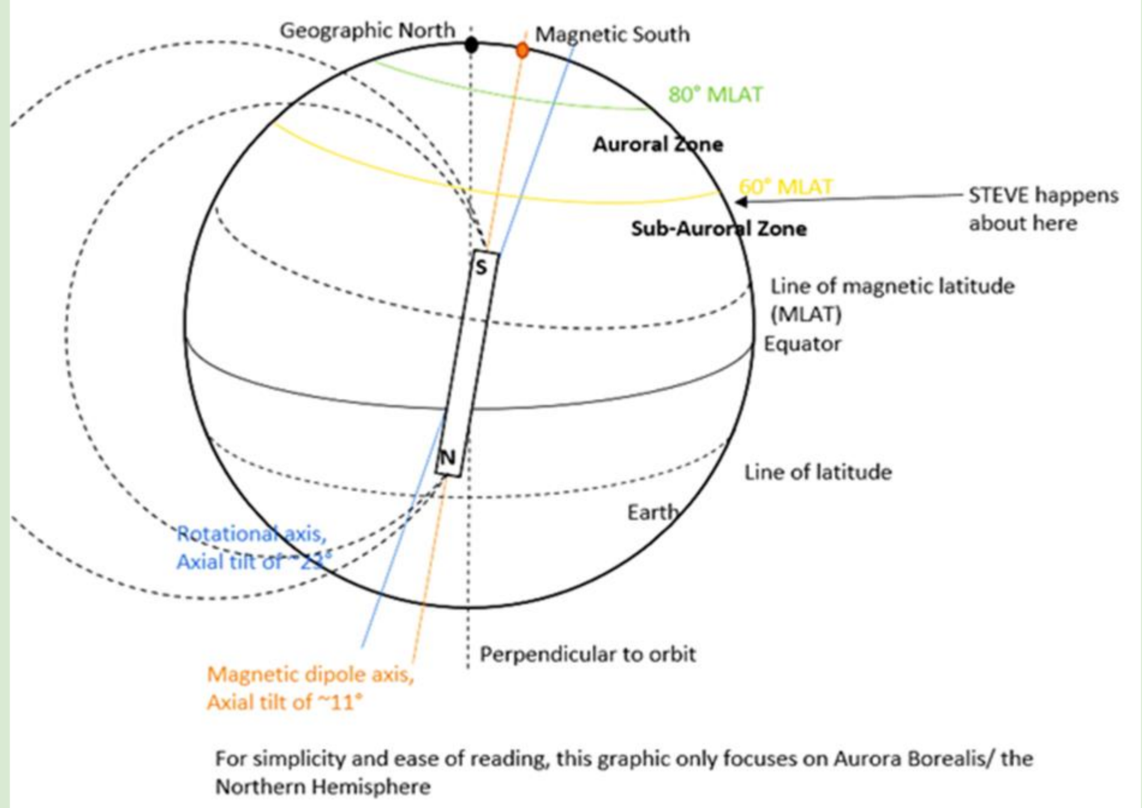
- STEVE forms due to subauroral ion drifts -
  - Also called polarization jets, form during substorms
  - Seasonal, coincides with space weather

back·ro·nym
/ˈbakrəˌnim/

noun

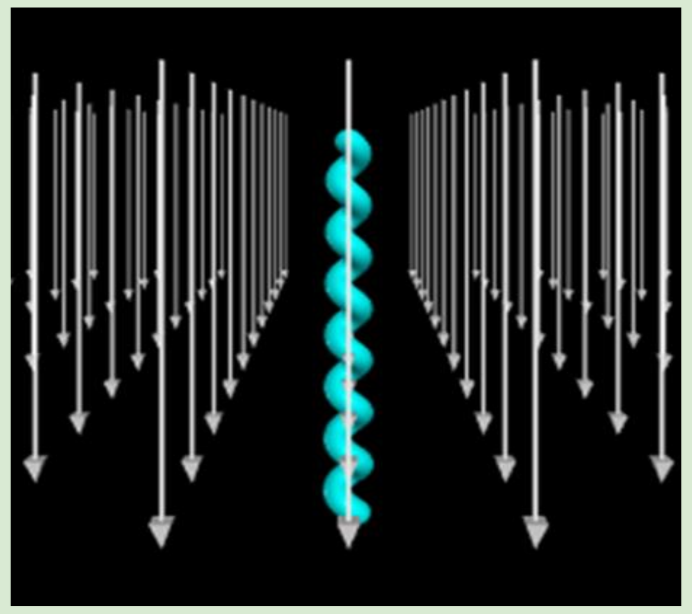
an acronym deliberately formed from a phrase whose initial letters spell out a particular word or words, either to create a memorable name or as a fanciful explanation of a word's origin.
"Biodiversity Serving Our Nation, or BISON (a backronym if ever there was one)"

Physics of Aurora Borealis



Representation of Earth's magnetic field in the dipole approximation model with indications of how and where auroras and STEVE form

Particle in Constant Field

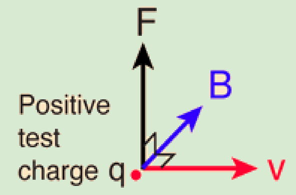


Representation of charged particle moving through uniform magnetic field, under effects of Lorentz force

How does a charged particle interact with a magnetic field?

- The particle experiences a force, called the Lorentz force, which is the cross product between the velocity of the particle and the magnetic field
- This causes the particle to spiral around the magnetic field

$$\vec{F} = q\vec{v} \times \vec{B}$$



Development of Model

Assumptions:

- Earth's magnetic field is a dipole magnetic field
- Only interaction between charged particle and earth's magnetic field is Lorentz force
- Earth radius is 1 and constant in magnetic field equations is 1
- Lorentz force is cross product between particle's velocity and the magnetic field at the particle's location

Overview of code:

- Set constants
- Define dipole equations in spherical and cartesian
  - Allows for different uses depending on convenience and necessity of coordinate system changes
- Make "set of particles"
  - We made a "new particle" for each update of position and velocity
- Show visual of magnetic field vectors for a range of distances from Earth
- Set particle's initial position and velocity
- Update position and velocity according to Lorentz force

```
def dipolespher(r,angle): #spherical coordinates
    B=np.zeros(dim)
    B[0]=-2*B_const*sin(angle)/(r**3) #r component
    B[1]=-B_const*cos(angle)/(r**3) #theta component
    #no phi component because there is azimuthal symmetry
    return B

def dipolecart(x): #cartesian coordinates
    B=np.zeros(dim)
    r = sqrt(x.x**2 + x.y**2 + x.z**2)
    B[0]=(-B_const*3*x.x*x.z/(r**5))
    B[1]=(-B_const*3*x.y*x.z/(r**5))
    B[2]=(-B_const*(2*(x.z**2)-(x.x**2)-(x.y**2))/(r**5))
    return B
```

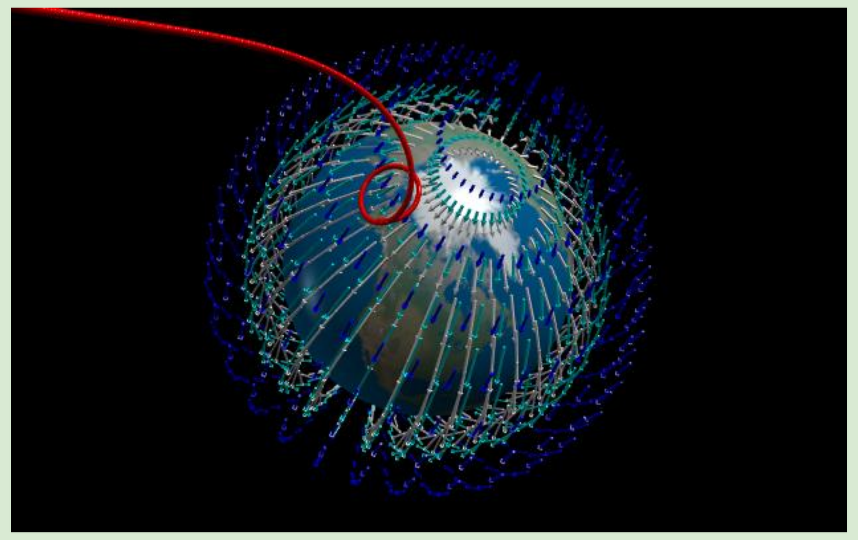
```
position = vector(1.1*earth_r,1.1*earth_r,0.7*earth_r)
velocity = vector(-0.05,0,0)
q = 1.0; t = 0; tf = 100000; dt = 0.1

while t < tf:
    makeparticle(position, velocity)
    for thisparticle in particles:
        acc=vector(0,0,0)
        B_field = dipolecart(thisparticle.pos)
        B = vector(B_field[0], B_field[1], B_field[2])
        F =cross((q*thisparticle.velocity), B)
        acc += F
        #updating velocity and position of particle
        thisparticle.velocity+=acc*dt
        thisparticle.pos+=thisparticle.velocity*dt
        t += dt
```

Particle in Dipole Field

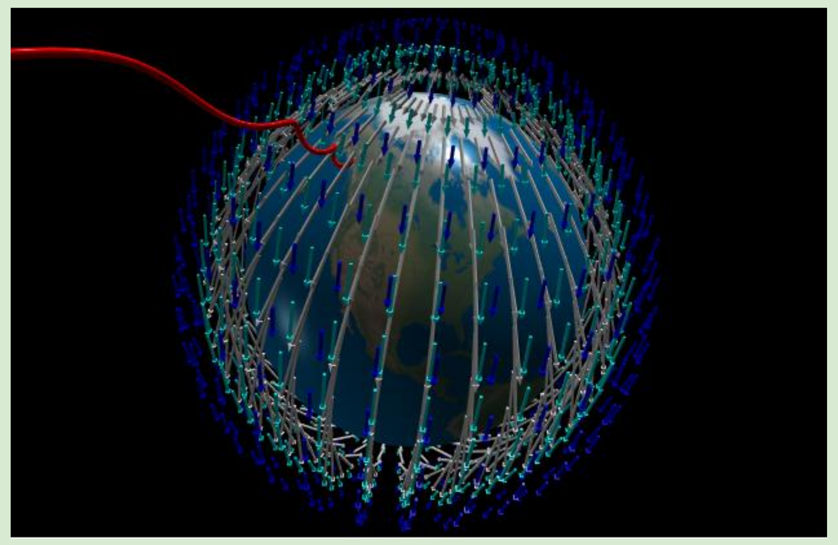
Comparison of Velocity and Position Parameters

Particles moving through Earth's dipole magnetic field from different starting positions and at different velocities

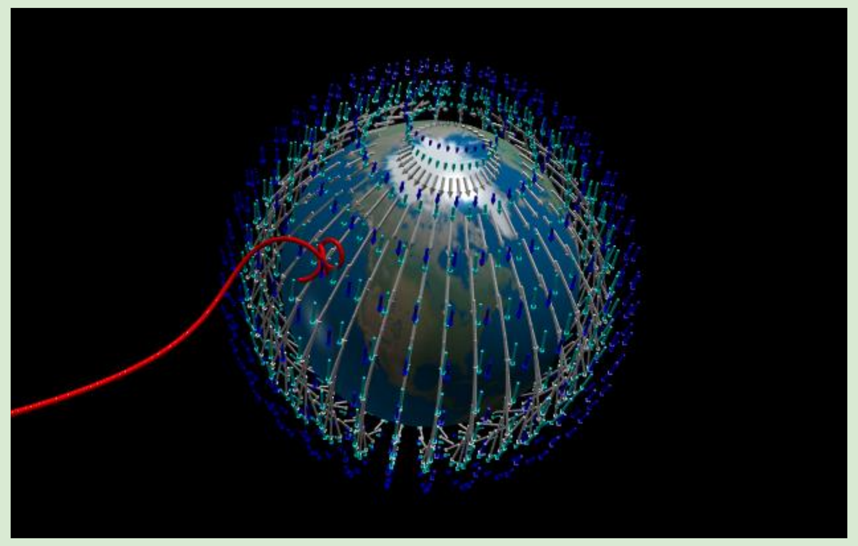
- We see that at sub-auroral latitudes, the aurora is more vertical, as we expect from descriptions of STEVE
- At higher latitudes, the aurora forms a curtain shape from many particles oriented sideways
- At greater speeds, the corkscrew wound by the particle has a larger radius → slower speeds wind tighter corkscrews



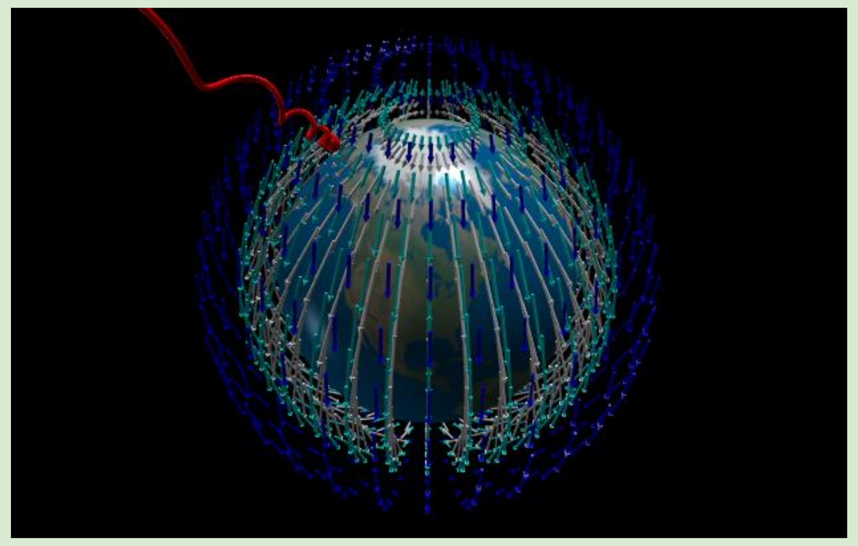
Approximately auroral latitude "Fast" velocity



Approximately sub-auroral latitude "Slow" velocity



Approximately sub-auroral latitude "Fast" velocity



Approximately auroral latitude "Slow" velocity

References

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Future Work

- Improve on model's assumptions that the particles only interact with the Earth's magnetic field and experience acceleration from the Lorentz force, as well as that the only magnetic field vector that matters is at the particle's location
- Auroras form due to plasma being trapped in certain regions of the atmosphere and interactions with various gases; our charged particles should be radiating
- Additionally, our model has the Earth's radius and the strength of the magnetic field set to one for simplicity; with more time, we could scale these values to realistic values
- Another addition could include the Earth's magnetic field experiencing a compression effect from solar wind that forms a "magnetotail" which would cause the charged particles to interact slightly differently
- Also would make code more efficient to have a trace on a single particle's motion instead of making a new particle for every update in position and velocity