Docent lecture

... include parts that my 1 year old daughter could understand
... include parts that nobody understands

after lecture - cake refreshments at 3rd floor

research
Reconnection in space

- Energy
- Magnetic field
- Reconnection concept
- Reconnection examples
- Reconnection research
For those who want some proof that physicists are human, the proof is in the idiocy of all the different units which they use for measuring energy.

Measuring energy

- atoms
- ions
- electrons
- photons

1 eV – infrared
2 eV – visible light
4 eV – ultraviolet
1 keV – X rays
1 MeV – gamma rays
**Sun**

Surface temperature $\sim 6000 \degree C$

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**Graph**: 
- $\lambda [\mu m]$ on the x-axis.
- $\lambda^{-2}$ (lambda squared) on the y-axis.
- Intervals: 0, 0.5, 1, 1.5, 2.

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**Energy Levels**:
- 1 keV
- 4 eV
- 8 eV
- 2 eV

---

**Images**:
- Sun surface
- Sun core
- Sun spectrum
Highest energies in space above the Sun!
Energy should come from somewhere!
Sunny day on Earth

Particle energies

<table>
<thead>
<tr>
<th>Location</th>
<th>°C</th>
<th>eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>on Sun</td>
<td>6000</td>
<td>0.5</td>
</tr>
<tr>
<td>space around Sun</td>
<td>$10^6$</td>
<td>100</td>
</tr>
<tr>
<td>on Earth</td>
<td>30</td>
<td>0.026</td>
</tr>
<tr>
<td>space around Earth</td>
<td>$10^3$-$10^8$</td>
<td>0.1-10000</td>
</tr>
<tr>
<td>center of Sun</td>
<td>15 $10^6$</td>
<td>1300</td>
</tr>
</tbody>
</table>
Ionization

Energy necessary to create an ion and electron from one atom

5-20 eV
Highest energies in space above the Sun!

Energy should come from somewhere!

Space is ionized – plasma!
Where are the highest energies in universe?
NGC 3079

Chandra X ray

Hubble optical

Credit: NASA/CXC/STScI/U.North Carolina/G.Cecil
Paris
sunny working day
Magnetic field

Think in magnetic field lines! .. without ends!
Magnetic flux tube energy $W$

Magnetic field lines

Magnetic flux tubes

Magnetic pressure

Magnetic tension

Magnetic energy converted into kinetic energy of ions and electrons

$W \geq W$
In space there are many places with much more energy in magnetic field than in ions and electrons. **Source of high energy particles?!**
Reconnection — the idea

✔ A narrow current sheet separates in space regions of different plasmas and oppositely directed magnetic field

✔ Reconnection — topology changes allowing interconnection of magnetic field lines from both regions. Two ways 1) $E \neq 0$, 2) $B=0$.

✔ Reconnection — energy conversion as a result of reconnection
Reconnection — the point

- **Topology** — allows energy and mass transport across boundary

- **Energy** — the magnetic field energy is built up by many particles but is converted to the kinetic energy of few which therefore receive high energies.

- **topology vs. energy**
Examples from space

Sun

Galaxies

Earth

Solar flare

Magnetic Field

Galactic halo

Proton aurora

Hard X-ray Sources

Galaxies

Soft X-ray Source

Sep 18 2000 02:58:44

Proton aurora

Galactic halo
Solar wind and Earth magnetosphere
Solar wind and Earth magnetosphere

Reconnection

Topology

Energy

Magnetopause energy transfer

Magnetotail energy storage (B)
Topology

Tsyganenko model
Solar flares

Xflare movie

Astrophysical jets

Jets from Young Stars
PRC95-24a - ST Sci OPO - June 6, 1995
C. Burrows (ST Sci), J. Hester (AZ State U.), J. Morse (ST Sci), NASA
Optical jets from young stars

Numerical simulations

[Hirose et al. 1997]
On a way to understand reconnection

✔ Theory
  - do the right approximations
  - give up and turn to numerical simulations

✔ Numerical simulations
  - take the right equations (MHD, HMHD, particles)
  - put into the code and study results

✔ Experiment
  - space in situ / astro / laboratory
  - most detailed observations from space in situ!
Reconnection — topics

- Structure
- Continuity
- Remote sensing
- Reconnection rate
- Guide field
- Relative importance
- Acceleration mechanisms (E)
- X-line

flows

reconnection jets

Numerical simulation [Rogers]
Numerical simulations

[Birn et al., 2001]

Reconnected flux
GEM challenge
Hall term important!
- whistlers
- Kinetic Alfvén waves

[out of plane magnetic field
- quadrupolar structure]

[ Rogers ]
**Numerical simulations**

Separatrices
- strong electric fields
- strong parallel currents
- electron beams

[Hoshino et al., 2001]
Reconnection jets

Reconnection & space physics

Phan et al., 2000

Solar wind

Equator-S

M’sphere

N_p (cm^{-3})

B_L (nT)

V_L (km s^{-1})

✔ Continuity

✔ Reconnection jets
Reconnection & space physics

Why space in situ: we can measure local magnetic and electric fields, as well as ion and electron distribution functions.

[Mozer et al., 2002]

[Retino et al., 2004]
Cluster chasing X-line

- 4 s/c ESA “Cornerstone”
- 2000-2005
- First time we can reliably solve time-space ambiguity
- First time reliable measurements of current

Current

2D

$c/\omega_p \sim 100\text{km}$

$c/\omega_e \sim 2\text{km}$

[Rogers et al., 2000]
Cluster, separatrices far from X-line

[André et al., 2004]

✓ Narrow strong current sheet
✓ e- beams
✓ Hall dynamics
Cluster, close to X-line

[Vaivads et al., 2004]

- Reliable structure estimate
- Hall dynamics
- Fast reconnection
Separatrices, $j_{\parallel}$ and HF waves

[Vaivads et al., 2004]

- Strong parallel currents
- Langmuir/upper hybrid emissions
- The role of waves? (anomalous resistivity, diffusion)

[Khotyaintsev et al., 2004]
Reconnection summary:

✓ Magnetic field **topology** changes and **energy** conversion
✓ Reconnection **jets**, plasma **energization**
✓ PLASMA (low energy) > B > plasma (**HIGH ENERGY**)
✓ In space around planets, stars, black holes, ...
✓ We start to understand **details**