The Sun and Space Weather

Paul Cassak
West Virginia University
Pulsar Search Collaboratory
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Image courtesy of SOHO
The Sun

• The Sun is a $4 \times 10^{26}$ (400,000,000,000,000,000,000,000) Watt light bulb

• Energy from the Sun keeps the Earth’s temperature at just the right place for liquid water to exist

• The entire food chain depends on plants getting light from the Sun
The “Quiet” Sun

- We tend to think of the Sun as steady and unchanging
  - We know from the geological record that the Sun cannot have changed much in the last 4 billion years!

The Sun on May 24, 2010, 2:19am
Solar Flares

- Solar flares are bursts of light from the solar atmosphere (the corona)
  - They emit off a lot of energy in a short time
    - Up to $10^{32}$ ergs
    - $3 \times 10^{18}$ kW-hr
    - Takes ~ 20 minutes
  - Compare -

   40 billion atomic bombs (!)

   2005 human energy consumption:
   1.4 $\times 10^{14}$ kW-hr

Image courtesy of SOHO
Discovery of Solar Flares

- Solar flares
  - Carrington, Sept. 1, 1859
  - Observing sunspots
  - “…two patches of intensely bright and white light broke out”
  - “…flurried by the surprise, I hastily ran to call someone to witness the exhibition with me, and on returning within 60 seconds, was mortified to find that it was already much changed and enfeebled.”
  - Later, there was a lot of auroral activity
    - Are the two related??
  - Went to a science meeting to share results
    - Hodgson saw the same thing
  - Both published an article about the event

From Carrington, 1859
http://adsabs.harvard.edu/abs/1859MNRAS..20...13C
The “Active” Sun

• Solar Eruptions
  – Solar flares
    • Burst of light
  – Coronal Mass Ejections (CMEs)
    • Material ejected
    • Discovered in 1971
  – The two often come together, but not always

Image courtesy of SOHO
Solar Eruptions

- Flares begin from a very small region of space
  - The associated CMEs are huge!

- CMEs release $10^{10}$ (10,000,000,000) tons of matter off the Sun
  - For comparison, the sun weighs $5 \times 10^{26}$ (500,000,000,000,000,000) tons!

From SOHO/TRACE/RHESSI
Image courtesy of SOHO
Very Recent Observations

Courtesy of Solar Dynamics Observatory
Launched February 2010, first observations March 2010
CME Effect on a Comet

- October 1, 2007, Inside Mercury’s orbit:

Comet Encke going through a CME

From the STEREO satellite, courtesy of NASA
CME Effect on Earth

- The Earth’s magnetic field “protects” us from the brunt of the impact, but the CME disrupts the Earth's field, causing a “geomagnetic storm.”
Result of Storms - Aurora

Carrington was right! Flares and auroral activity are related!
Impact - Space Weather

- Astronaut safety: 500 km
- Atmospheric drag
- Solar cell damage: 20,000-35,000 km
- Radio wave disturbance
- Electricity grid disruption
- Telecommunication cable disruption
- Signal scintillation
- Airline passenger radiation: 10 km

$R_E \sim 6400$ km
Space Weather Effects

A CME occurred on August 7, 1972. The Apollo 16 and 17 missions were in April and December of 1972.

A CME on March 9, 1989 caused a storm which destroyed power grids in Quebec on March 13, 1989.
How to study Sun & Space Weather

• Direct observations
  – Solar satellites
  – Magnetospheric satellites
  – Ground-based detectors

• Laboratory studies
  – Build an experiment

• Theoretical/Numerical studies
  – Learn a lot of physics
  – Write/run large computer codes
Conditions in the Sun & Space

- Matter is in the "plasma" state.
  - It’s so hot that atoms break apart into electrons and ionized particles (ions)
  - Some say 99% of observable matter in the universe is in the plasma state
  - Plasmas are unique because they are greatly influenced by magnetic fields
Close-up Movie of the Corona

Hinode (Solar-B) satellite data of “magnetic carpet”
A Wide Range of Plasmas
Space Weather Research

- The major goal of space weather research is to predict space weather (CMEs, geomagnetic storms) much like we predict the weather!
Conclusions

• The solar corona is home to the largest explosions in the solar system (solar flares and coronal mass ejections)

• CMEs bombarding earth have an important impact on the Earth’s environment, some detrimental
  – The attempt to forecast these events is called “space weather”

• Plasma physics is the tool of choice to study space weather

• Contact me - Paul.Cassak@mail.wvu.edu