Interested in Astronomy Research?

- Now accepting applications for academic-year research fellows
- Fellows will search for exotic objects called pulsars and join an international research collaboration
- Visit the National Radio Astronomy Observatory and use the Green Bank Telescope
- Attend a scientific research meeting at Arecibo Observatory in Puerto Rico (expenses paid)
- Students of all levels and experience invited to apply
- Visit pulsar.wvu.edu to learn more and apply by **October 3**
Test #1

Monday, October 6, 11 - 11:50 am
Chem 305 (classroom)
Bring pencils, paper, calculator

~2/3 Quantitative Problems (like homework problems)

~1/3 Qualitative Questions
Multiple Choice, Short Answer, Fill In the Blank questions
No essay questions
The Sun: A Star of Our Own
ASTR 2110
Sarazin
Photospheric Spectrum
Photospheric Spectrum

General result

Stellar spectra = continuum emission + absorption lines
Photospheric Spectrum

• Wavelengths of lines $\rightarrow$ bigger opacity, smaller mean-free-path
• Don’t see in as far

- cooler absorption lines
- hotter continuum emission
- center
Solar Atmosphere

- **Photosphere**
- **Chromosphere**
  - Hotter 10,000 K
- **Corona**
  - Very hot, millions K
  - Extends out very far
Solar Corona
Solar Atmosphere

- Photosphere
- Chromosphere
- Corona
- Solar Wind
What heats the corona and chromosphere?

Not completely understood, but almost certainly due to magnetic fields.
Charged Particles in Magnetic Fields

Helical motion

\[ \vec{F} = \frac{q}{c} (\vec{v} \times \vec{B}) \quad q = \text{charge} \]

Work \[ = -\int \vec{F} \cdot d\vec{r} = -\int \vec{F} \cdot \vec{v} \, dt = 0 \]

\( E = \text{constant}, \text{thus} \ KE = \text{constant} \)

\( |\vec{v}| = \text{constant} \)

In plane \( \perp \vec{B} \), circle orbit

\[ r_g = \frac{mv_{\perp}c}{qB} \quad \text{gyro radius} \]

\( v_{\perp} = \text{constant}, \ v_{||} = \text{constant} \)

Helical motion
Bulk Properties of Plasma with Magnetic Field

Faraday’s Law: changing magnetic field → electric field → current (if conductor)

Ampere’s Law: current → magnetic field

Acts to prevent change in magnetic field B
Bulk Properties of Plasma with Magnetic Field

Can’t pull wire from B field
Plasma = like wires in all directions
“Frozen-In Condition”

Plasma and Magnetic Field are locked together
“Frozen-In Condition”
plasma and magnetic field tied
Who is master and who is slave?
Bigger pressure wins.
Gas pressure $P_{\text{gas}} = n k T$
Magnetic pressure $P_B = B^2/(8\pi)$
Solar Activity

- Sunspots
  - Galileo 1613
  - Dark $\rightarrow$ Cool (4000K, not 6000K)
  - Pairs (east-west)
Sunspots
Sunspots

Size of Earth
Solar Activity

- Sunspots
- Prominences
Solar Prominence
Sep. 14, 1999
Solar Activity

- Sunspots
- Prominences
- Flares
  - Giant explosions on Sun
  - Shoot out dangerous particles
Solar Flare

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Solar Flare

Approx. size of Earth
Solar Activity

- Sunspots
- Prominences
- Flares
- Occur together in active region
Solar Magnetic Field

- Sun’s magnetic fields stronger than Earth
- Causes solar activity
- Field ~1000x stronger in sunspots, active regions
Magnetic Field, Corona, and Solar Wind

Deep in Sun, density, temperature, pressure high, $P_{\text{gas}}$ big $\rightarrow$ magnetic field anchored in Sun
Further out, pressure low, magnetic field controls gas
No magnetic monopoles $\rightarrow$ field lines never end

Closed Loops:

hold plasma = corona
Magnetic fields trap gas.

sunspots

$T \approx 4,500\,\text{K}$

$T \approx 5,800\,\text{K}$

convection cells

Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.
Magnetic Field, Corona, and Solar Wind

**Solar Flares**: Magnetic loops break, “reconnect”
Magnetic Field, Corona, and Solar Wind

Closed Loops:

hold plasma = corona

Open Loops:

gas leaves = no corona, solar wind

Solar Wind comes from “coronal holes”
Coronal Hole

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Sun Spots and Magnetic Loops

Magnetic fields trap gas.

T = 5,800 K

sunspots T ≈ 4,500 K

T ≈ 5,800 K

convection cells

Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.
Sunspot pairs opposite magnetic polarity
Magnetic field reverses every 11 years

Electromagnetic “dynamo” field
Sunspots and Solar Cycle
Solar Cycle

• Number of sunspots, other activity $\rightarrow$ maximum every 11 years
Solar Cycle

• Number of sunspots, other activity → maximum every 11 years
• Magnetic reversal → 22 year solar cycle
Butterfly Pattern

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)

DATE

AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)

DATE
Butterfly Pattern
Solar Dynamo Magnetic Field