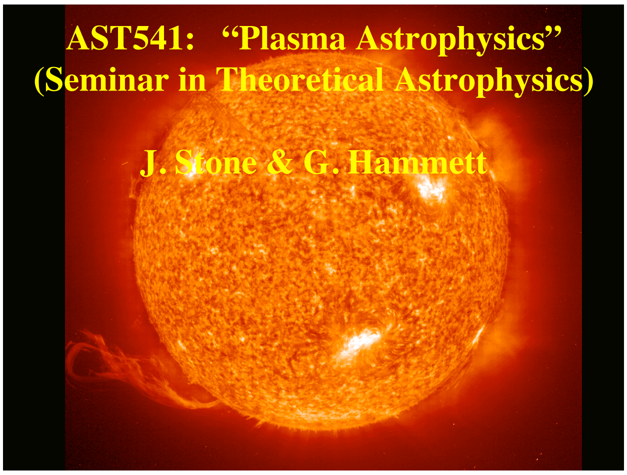

Our coordinates.

Jim Stone
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Peyton 125

Greg Hammet
hammett@princeton.edu
A137 PPPL

Course webpage:
http://www.astro.princeton.edu/~jstone/AST541

Course Structure.

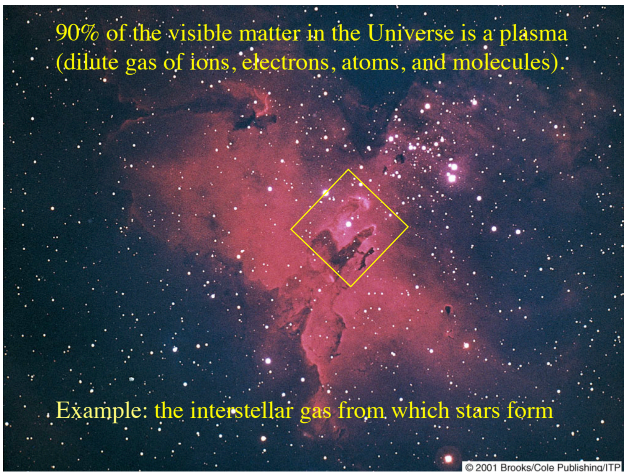
Similar to previous years:

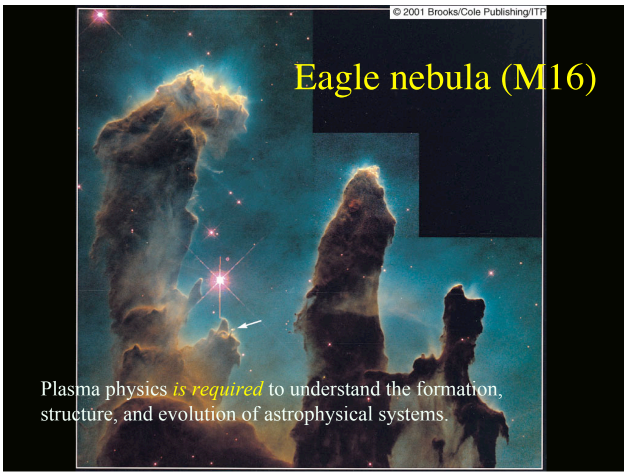
- All Astro students must make one 1/2-hour presentation during semester.
- Everyone must attend all lectures, and participate by asking questions.
- Everyone must provide feedback to presenters by written comments.
- Course is P/F. You will pass if you participate.

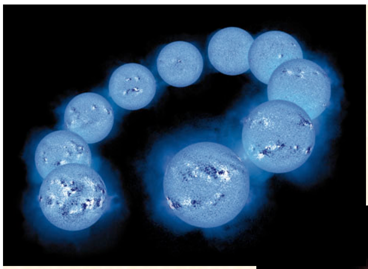
Presentation:

- Based on topics you chose.
- We will provide references to fundamental papers. Either summarize just these papers, or include results from a larger literature search.
- Must meet with us Fri or Mon before presentation to go over slides.

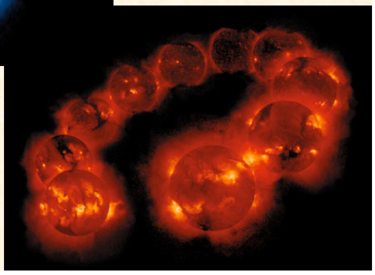
Why "Plasma Astrophysics?"



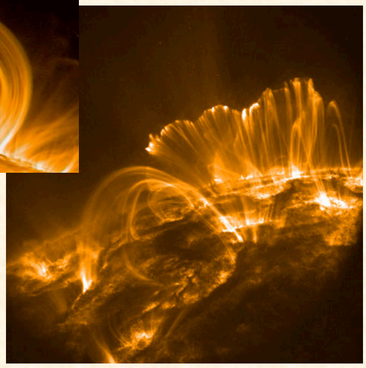




Topic #1:
Dynamos



Dynamo in solar interior drives solar cycle.

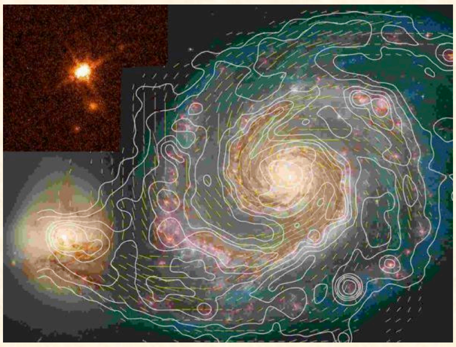


Magnetic field generated by dynamo produces solar activity.

Also see movie of "polar crown prominences":
http://science.nasa.gov/science-news/science-at-nasa/2008/17sep_polarcrown/

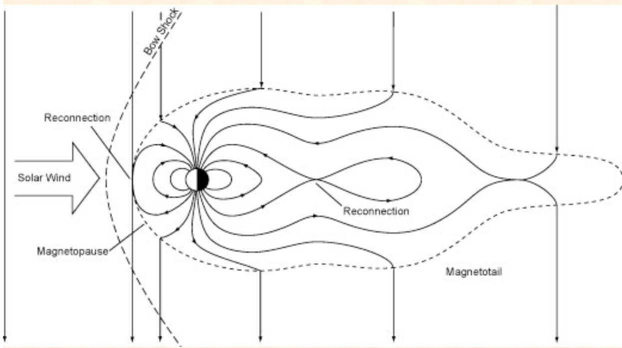
Dynamo creates magnetic field in galaxies

Synchrotron radiation and polarization vectors in M51 (whirlpool galaxy)



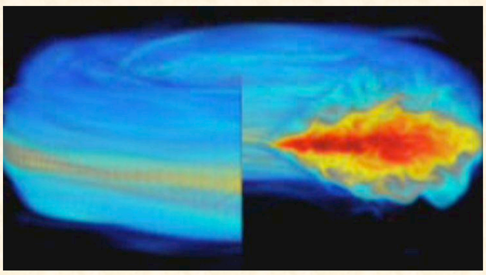
Topic #2: Magnetic Reconnection

In Earth's magnetotail, observed to accelerate electrons to relativistic speeds



Topic #3. MRI

MRI and other plasma instabilities explain transport and accretion in disks.



Hawley & Balbus et al., Computer Simulation of Magneto-Rotational Instability Turbulence
http://www.astro.virginia.edu/~jh8h/
http://www.astro.virginia.edu/VITA/papers/torus3d/densityminchunk.mpg

Topic #4: MHD turbulence controls the structure of the interstellar medium.

Carina Nebula

Hubble Heritage

Topic #5: kinetic MHD.

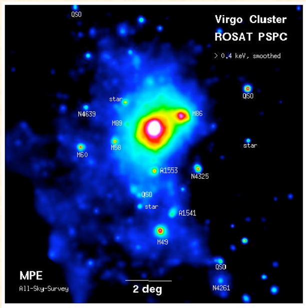
An intermediate regime between
1. continuum (fluid) approximation ($\lambda \ll L$)
2. collisionless plasma physics ($\lambda \gg L$)

Kinetic MHD (long mean-free path regime):
$L \gg \lambda \gg \rho$ (gyro-radius), low ω (MHD).

Relevant in diffuse plasmas…

X-ray emitting plasma in clusters of galaxies.

Virgo cluster (optical)



Virgo cluster (X-rays)

T ~ 4.5 keV, n ~ 10^{-3}-10^{-4} cm^{-3}, B~ 1μG implies $\lambda_{mfp} \sim 0.1 R_V$
$\rho \sim 10^8$ cm

Advances in simulation driven by new hardware.

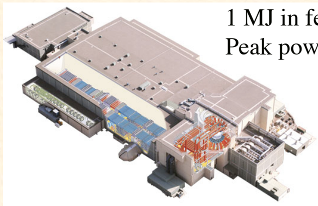
There are 5 machines on top500.org list above 1 Pflop.

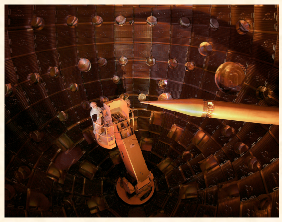
For example, RoadRunner with 122,400 cell processors at Los Alamos National Laboratory.

1026 Tflops (1Pflop!!) sustained performance.

New experimental facilities: NIF

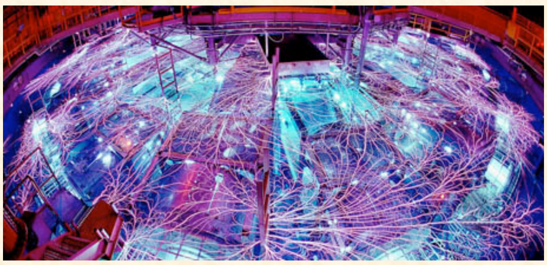
192 lasers focused on 1mm target
1 MJ in few nanoseconds.
Peak power is 500x US energy supply





New experimental facilities: Z-machine

26 Mamps pulsed through cm-sized wire array
350 Twatts produces 2 GK plasma.



For more details of emerging research topics in Plasma Astrophysics, see WOPA report: http://www.pppl.gov/conferences/2010/WOPA/

Page 7 of WOPA report

This effort brought together observers, experimentalists, computational plasma physicists, and theorists from universities, national laboratories, government research institutions, and private industry, including several scientists from outside the U.S. It also encompassed physicists studying magnetized plasmas and those studying high energy density plasmas. The breadth of participation uncovered cross-cutting opportunities previously unappreciated. This document reports the results from the workshop.

MAJOR QUESTIONS AND TOPICS

There are two approaches to articulating the challenges and opportunities: through plasma processes or through astrophysical systems. Individual plasma processes affect multiple systems, and individual systems encompass multiple processes. We have taken both approaches. Each of the ten working groups focused on one of the following processes that express the physics challenges (listed here in random order):

- Magnetic reconnection
- Collisionless shocks and particle acceleration
- Waves and turbulence
- Magnetic dynamos
- Interface and shear instabilities
- Angular momentum transport
- Dusty plasmas
- Radiative hydrodynamics
- Relativistic, pair-dominated and strongly magnetized plasmas
- Jets and outflows

Discussion of these topics, and their links to astrophysics, constitutes the bulk of this report. From these studies, we then extracted ten major, system-based questions for plasma astrophysics (listed here in random order):

How do magnetic explosions work?
Astrophysical plasmas exhibit spontaneous "explosions," such as solar flares, stellar flares, and substorms in planetary magnetospheres. These events accelerate particles to high energy, and affect radio communications on Earth. The explosions are driven by magnetic reconnection, the physics of which must be unraveled to understand why energy contained in magnetic fields of stars and planets is released explosively, and how this energy is so efficiently converted to particle energy.

How are cosmic rays accelerated to ultra-high energies?
Energetic particles bombard the Earth from space with energies up to 10^{20} electron volts, enormously more energetic than those achieved in the most powerful accelerator in the laboratory.

7

Schedule of lectures.

Today: basic introduction to plasma physics.

- Plasma parameters (length and time scales)
- Single particle motion
- Ideal MHD, flux freezing
- Generalized Ohm's Law
- MHD and Plasma waves

Remaining lectures:

See webpage and handout.