ASTR 1040: Stars & Galaxies

Pleiades Star Cluster

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Lecture 9 Tues 11Feb 2020

zeus.colorado.edu/astr1040-toomre

Topics for Today and Thur+

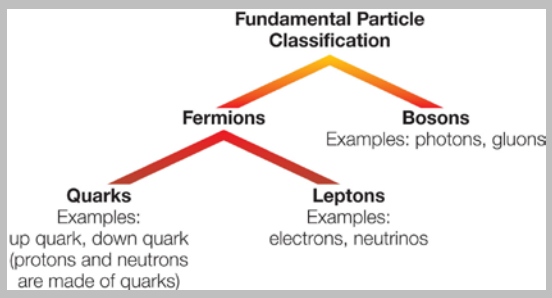
- Revisit solar magnetism and its cycles
- Use of supercomputers to simulate dynamics within the Sun
- Effects of solar magnetism on Earth

- What can we measure in other stars?
- How do we begin to classify other stars?
- Why temperature and spectral lines are closely linked in classifying stars O B A…M

Logistics

- Overview read Chap 15: Surveying the Stars
- Review Session Wed (tomorrow) 6-8pm here (G130) –- Max Weiner
- Mid-Term Exam 1 Thurs in class (see rules in Review Set #1, still available)
- Homework #3 (+answers) returned today

Recitation last week: S4.1 and S4.2



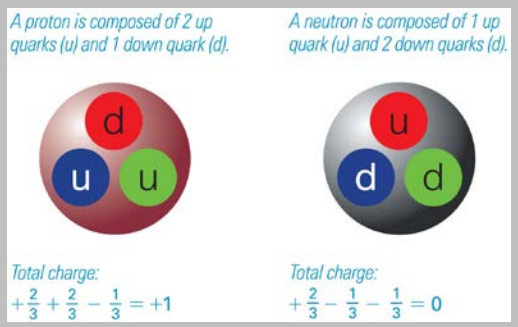
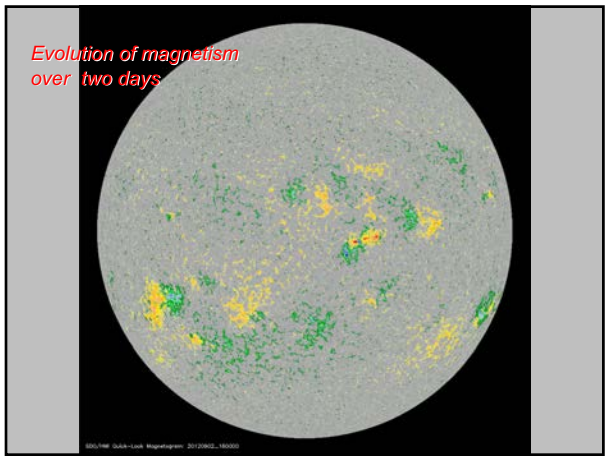
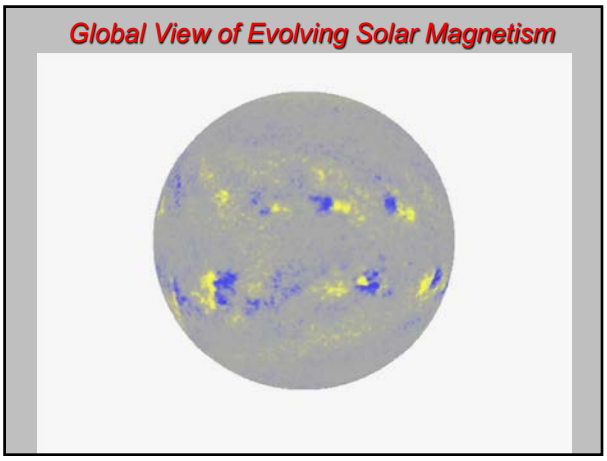
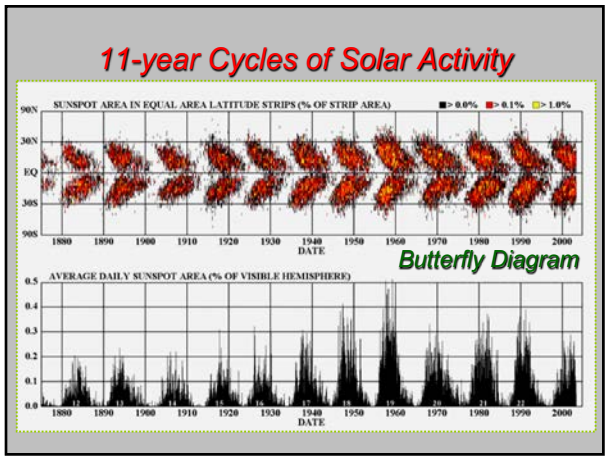


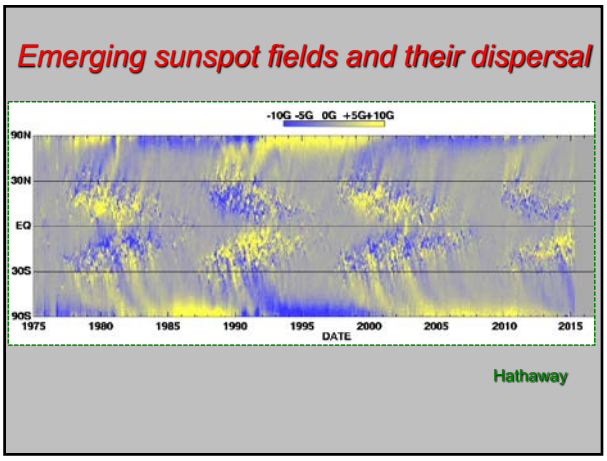
TABLE S4.1 Fundamental Fermions

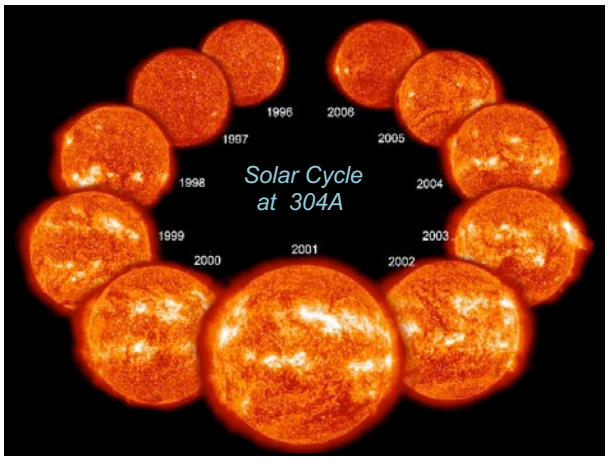
The Quarks	The Leptons
Up	Electron
Down	Electron neutrino
Strange	Muon
Charmed	Muon neutrino
Top	Tauon
Bottom	Tau neutrino

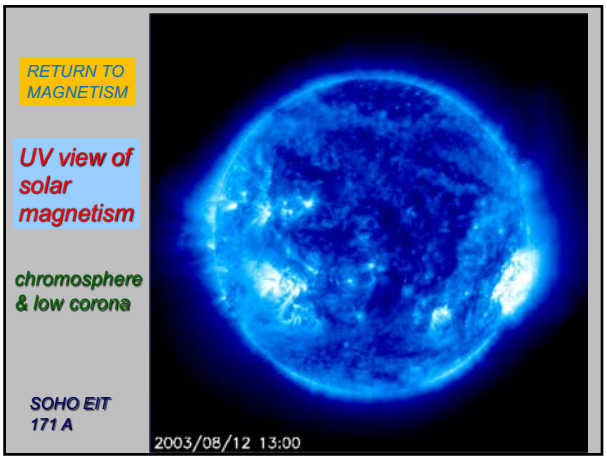

Evolution of magnetism
over two days

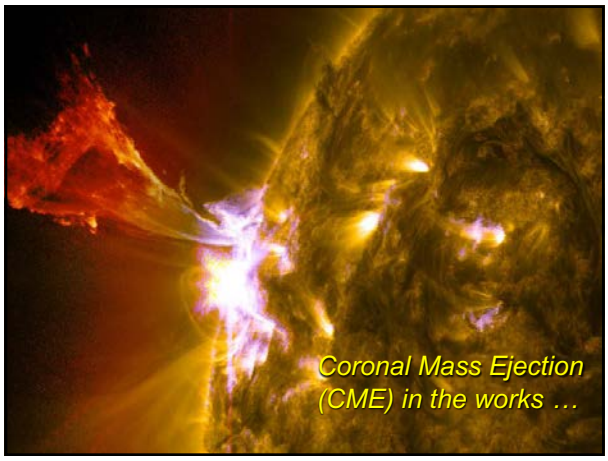

Global View of Evolving Solar Magnetism


11-year Cycles of Solar Activity
SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)
90N
30N
EQ
30S
90S
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
DATE
Butterfly Diagram
AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)
0.5
0.4
0.3
0.2
0.1
0.0
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
DATE

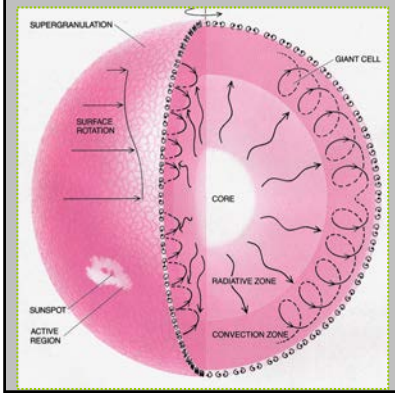

Emerging sunspot fields and their dispersal
-10G -5G 0G +5G+10G
90N
30N
EQ
30S
90S
1975 1980 1985 1990 1995 2000 2005 2010 2015
DATE
Hathaway


1996
2006
1997
2005
1998
2004
1999
2003
2000
2001
2002
Solar Cycle
at 304A


RETURN TO
MAGNETISM
UV view of
solar
magnetism
chromosphere
& low corona
SOHO EIT
171 A
2003/08/12 13:00



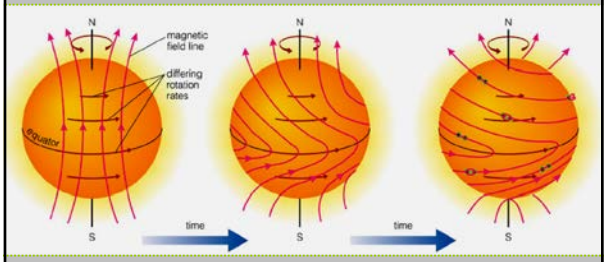
Magnetic fields are built in convection zone



Convection Zone: ROTATING SHELL OF TURBULENT PLASMA

Differential Rotation and Magnetic Dynamo …… go HAND-IN-HAND

How differential rotation can stretch and change global magnetic fields



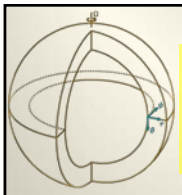
BUT THIS IS TOO SIMPLISTIC ….

Reasoning Clicker Q

B.

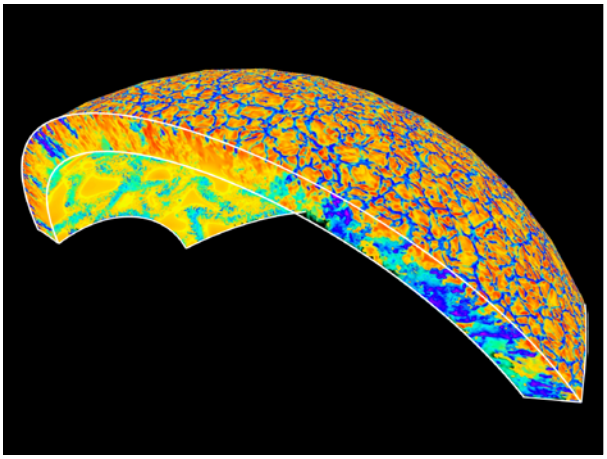
- *If the Sun's core went out of balance and shrank a little, what would happen there?*

- *A.* Density would decrease and fusion would slow down, releasing less energy
- *B.* Density and temperature would increase and fusion would speed up, releasing more energy
- *C.* The whole Sun would eventually shrink and thus core would come back into balance
- *D.* Not much would really change, so nothing to worry about

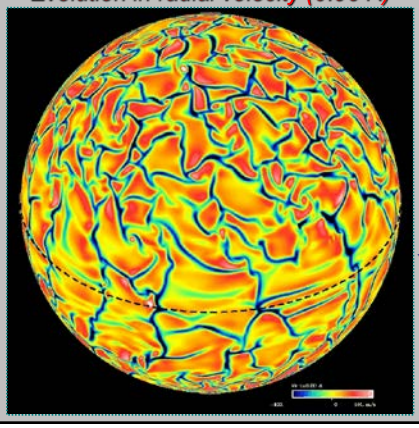


Supercomputer simulations:
Global convection & dynamo building of magnetic fields

- *Study turbulent convection interacting with rotation in bulk of solar CZ: 0.72 R - 0.97 R*
- *Realistic solar mean stratification*
- *Simplified physics: perfect gas, radiative diffusivity, compressible, subgrid turbulent transport*
- *Correct global spherical geometry: full or partial shell*



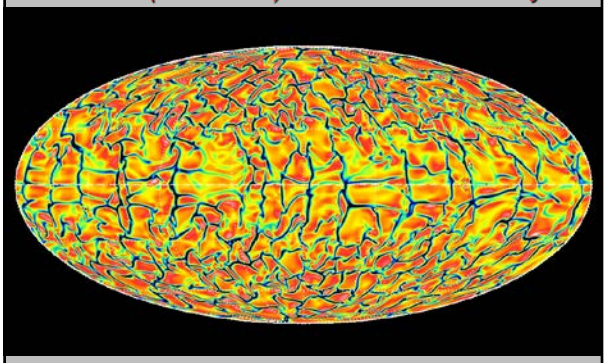
Evolution in radial velocity (0.96 R)



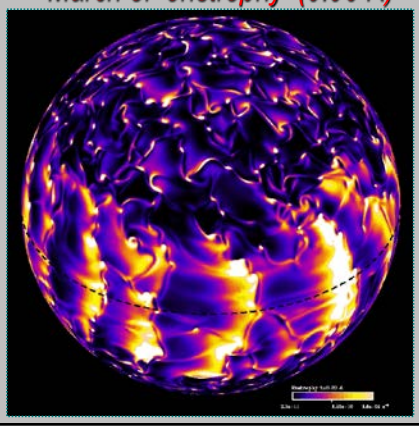
NEAR TOP OF LAYER

VIEWED IN 'CARRINGTON' FRAME

Global (Mollweide) view of radial velocity



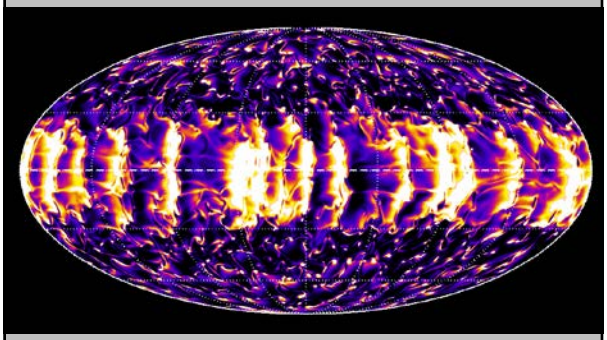
March of enstrophy (0.96 R)



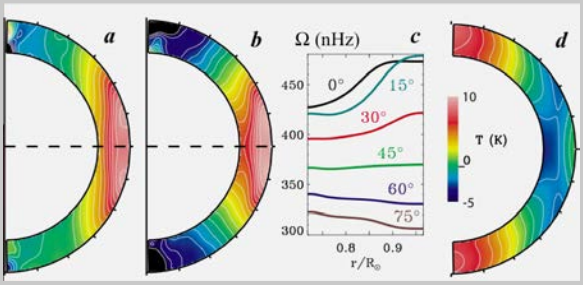
VORTICITY SQUARED

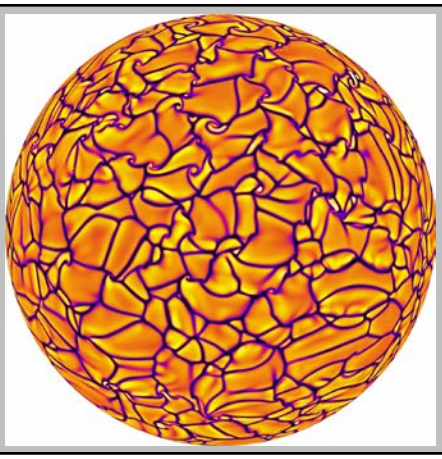
NEAR TOP OF SHELL

Global view of enstrophy



Resulting differential rotation built by convection: fast equator, slower poles





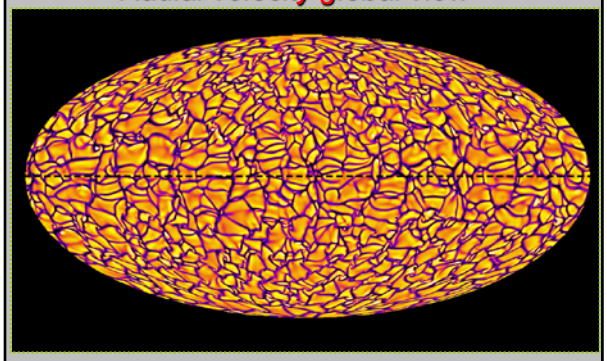
At highest resolution

Radial velocity

Case F

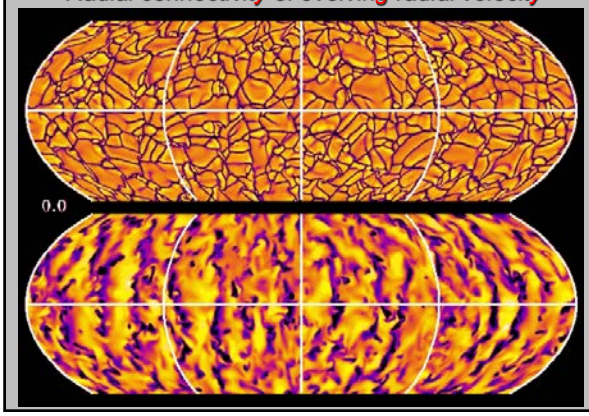
Miesch et al 2008, 2011

Radial velocity global view

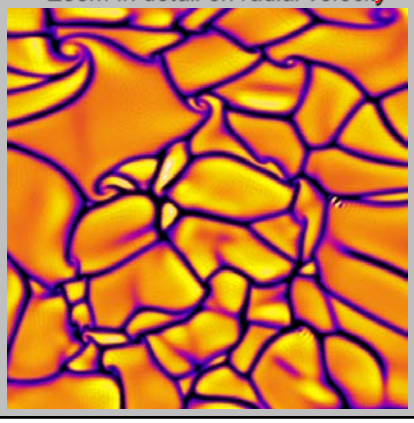


Case F

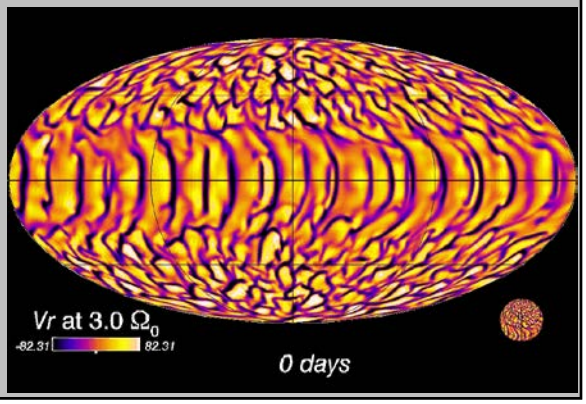
Radial connectivity of evolving radial velocity



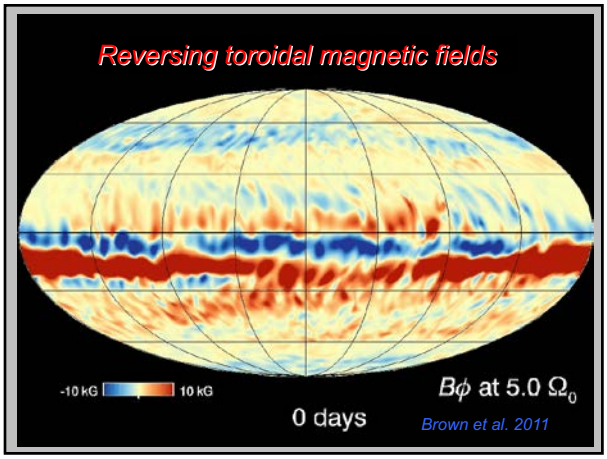
Zoom-in detail on radial velocity



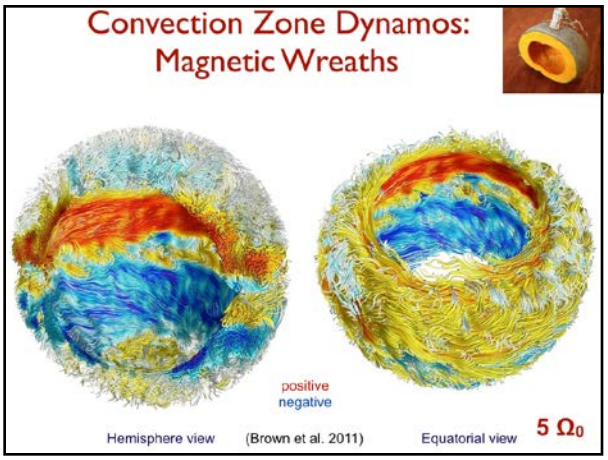
Now allow MHD dynamo to be turned on

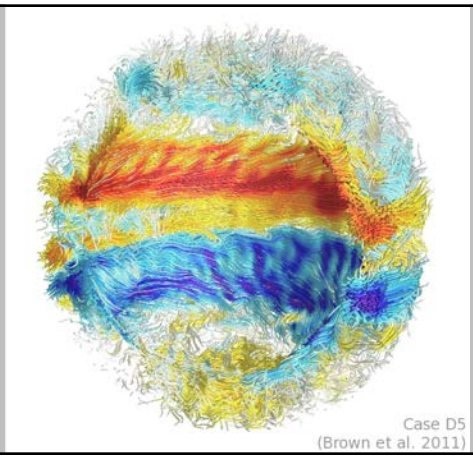


Reversing toroidal magnetic fields

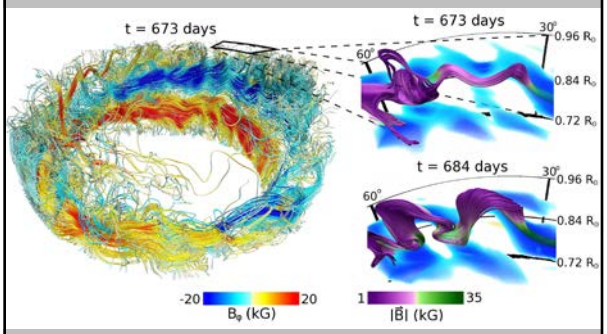


Convection Zone Dynamos: Magnetic Wreaths





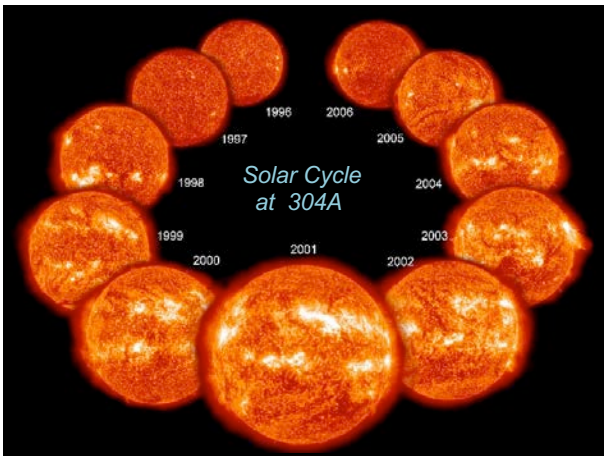
Buoyant magnetic loops ….
may emerge as sunspot loops



Let us make some plasma!
Demo of TESLA COIL

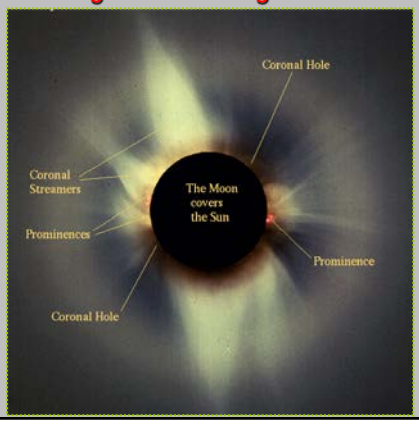
(Nikola Tesla, not just Musk's all-electric car!)

Powerful electric fields reach out



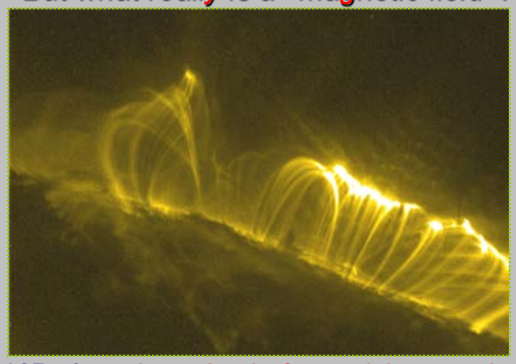
EUV from SOHO

Largest-scale magnetic fields



Sunspots at surface yields huge magnetic structures in corona

But what really is a "magnetic field"?



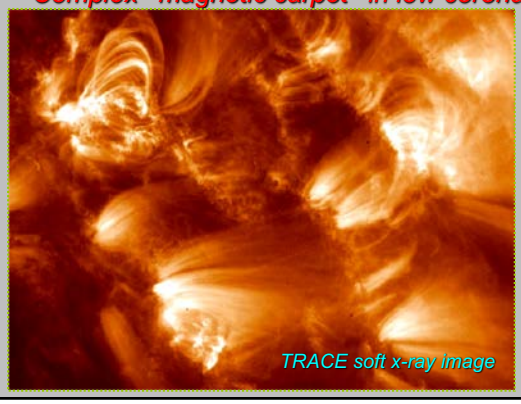
TRACE soft x-ray image: Arcade of magnetic loops on solar limb

Reading Clicker Question

Which is the most likely cause of the extreme heating in the chromosphere and corona?

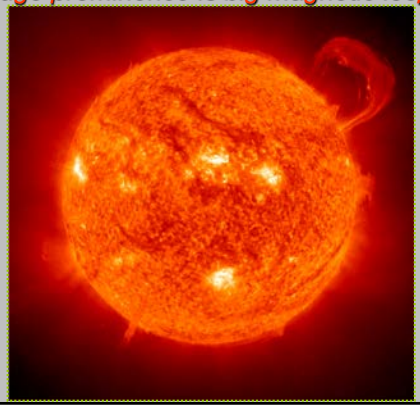
A. Energy deposited by magnetic fields
B. Heat rising from the surface of the Sun
C. Photons created at the photosphere interacting with the solar atmosphere
D. Neutrino interactions with the solar wind
E. Ionization of hydrogen just above the surface

Complex "magnetic carpet" in low corona

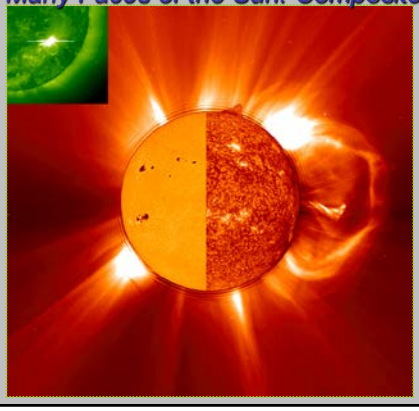


Magnetic Reconnection and Splendid Loops from SDO

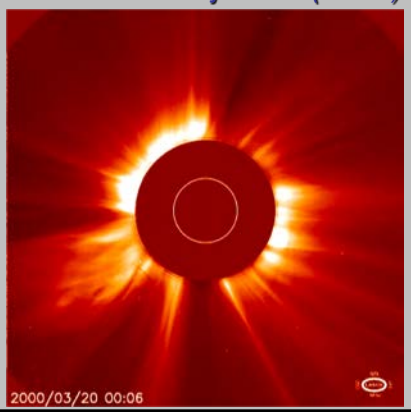
Huge prominence is big magnetic loop



Many Faces of the Sun: Composite

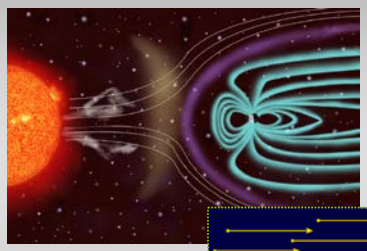


Coronal Mass Ejections (CMEs)

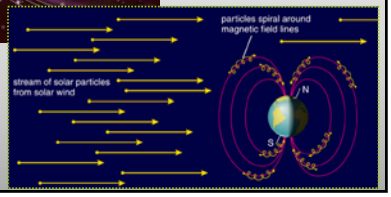


Combo: CME and UV disk

Solar Wind and Earth's Magnetosphere



Earth's Magnetic Field
Is Shaped by Solar Wind



Solar Wind and Aurorae

Northern Lights
(Aurora Borealis)