Wild Sun!

A Drama in Three Acts

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Middlebury College

Insight Cruises/Scientific American

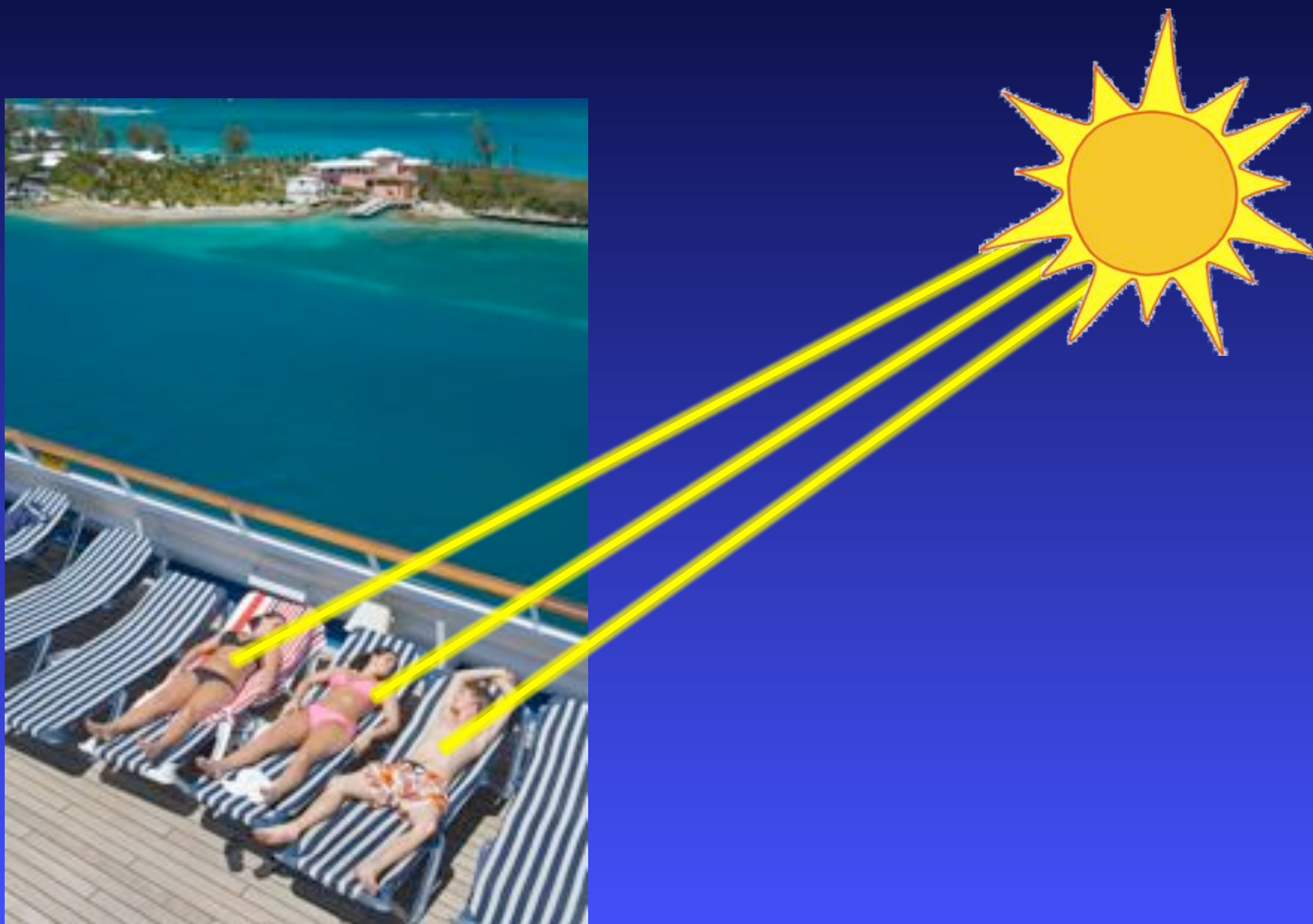
January 16, 2012

Wild Sun!
A Drama in 3 Acts

- Act 1: October Storm
  - Scene 1: At Earth, October 2011
  - Scene 2: At L1
  - Scene 3: On the Sun, 2 days earlier
- Act 2: A Tale of Two Atmospheres
- Act 2: Sun-Earth Connection

Prelude

Your relationship with the Sun



Act 1: October Storm

Scene 1

At Earth

Late October 2011

In the News…

Epic Geomagnetic Storm Erupts
Discovery News 10/25/11

Northern Lights Seen Across Southeast US
ABC News 10/25/11

Sun Storm Paints the Night Sky
Washington Post 10/26/11

Unusual Northern Lights Set Southern Skies Afire
*Roanoke Times*10/26/11

Watch Out Mars!
spaceweather.com 10/22/11

Solar Flare Illuminates the Grid's Vulnerability
New York Times 6/9/11

At Earth, October 24, 2011

Ozark, AK

Saskatoon, SK, Canada

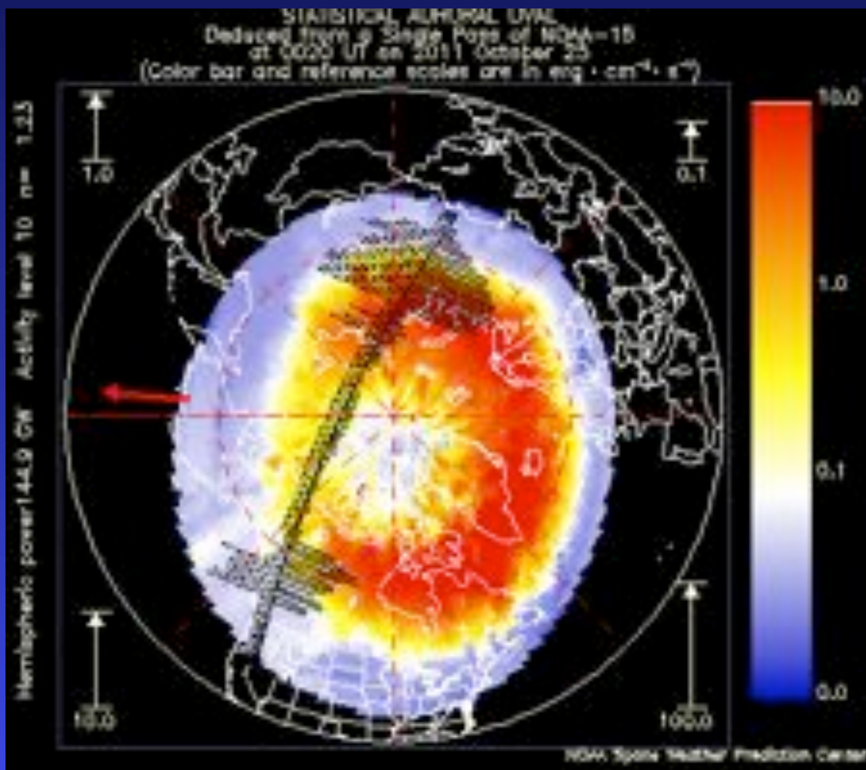
Marquette, MI

http://spaceweather.com/aurora/gallery_01oct11.htm

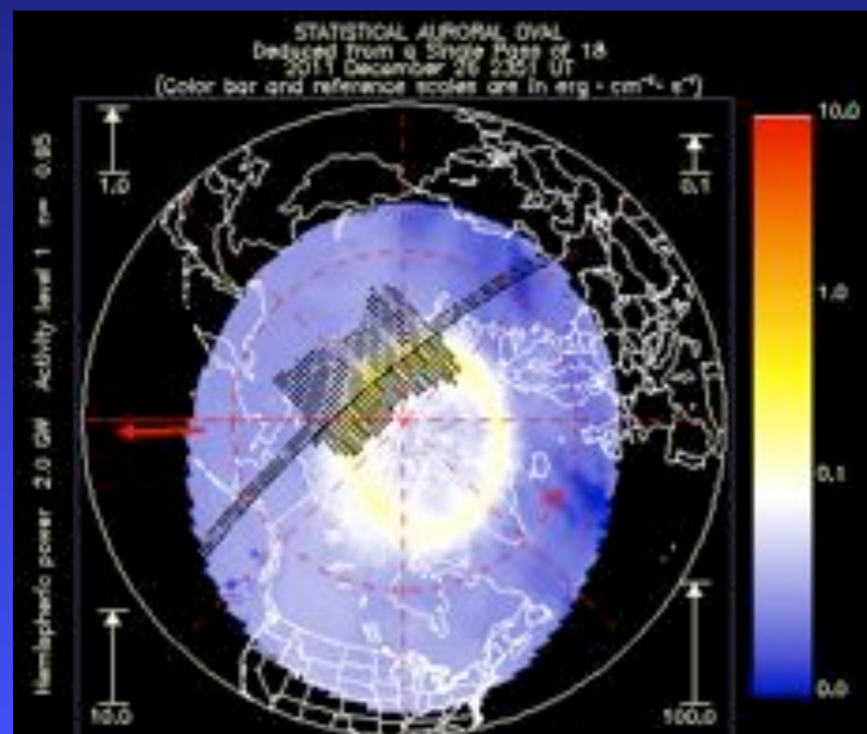
View From Over the Pole

Auroral oval from NOAA-15 satellite

October 25, 2011



December 26, 2011



Energy deposition, erg/cm^2/s

Act 1
Scene 2

At L1
(Late October 2011)

What’s L1?

Quick Quiz: What’s L1?

a) A stable point 60˚ ahead of Earth in the same orbit
b) A point directly behind the Moon
c) A point where Earth’s and Sun’s gravitational forces cancel
d) None of the above

What’s L1?

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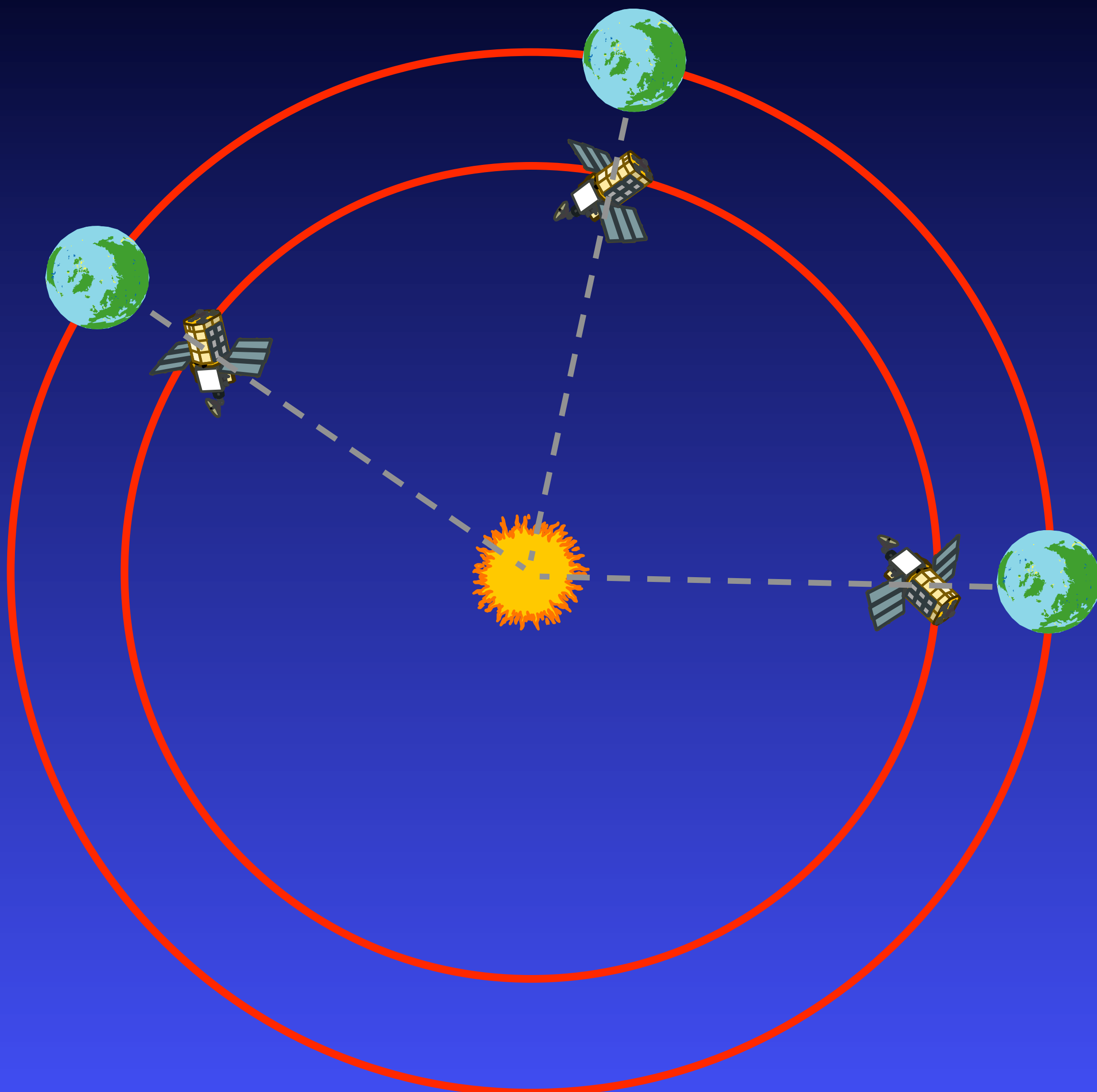
The L1 Lagrange Point

- Point where Earth's and Sun's gravity combine to give 1-year orbital period

- Located ~1 million miles sunward of Earth

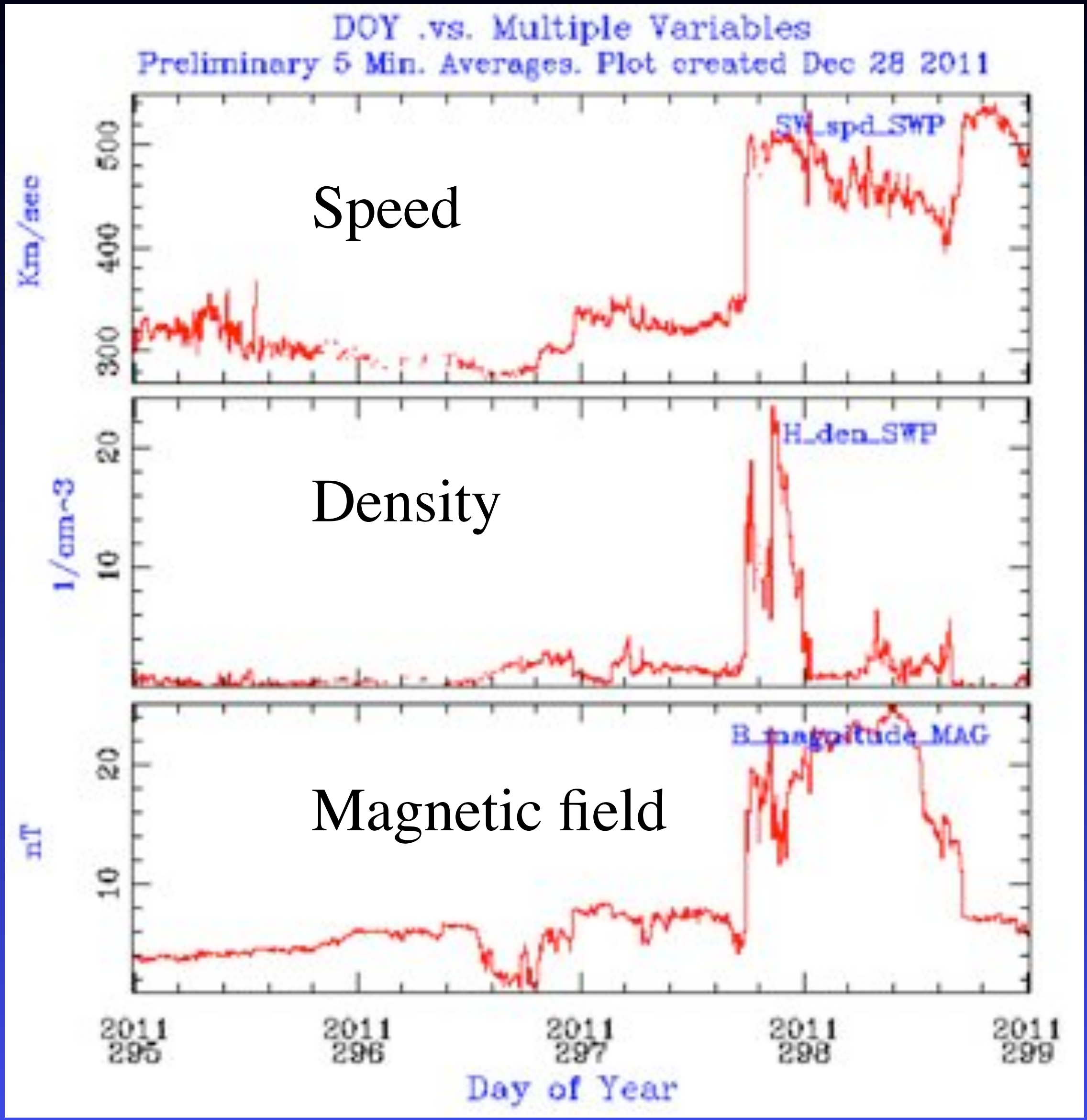
- Spacecraft at L1 orbit Sun in "lockstep" with Earth

- Sun always in view



At L1

ACE (Advanced Composition Explorer) solar wind data, late October 2011



Day of Year: 295 = October 22, 2011

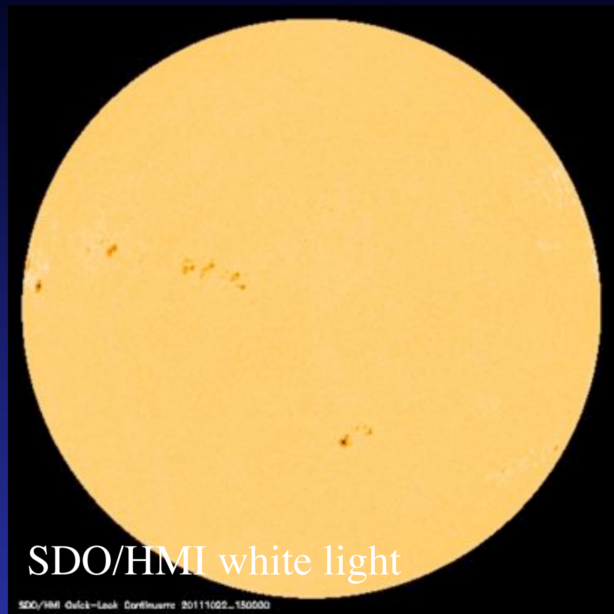
Graph constructed from http://www.srl.caltech.edu/ACE/ASC/browse/view_browse_data.html

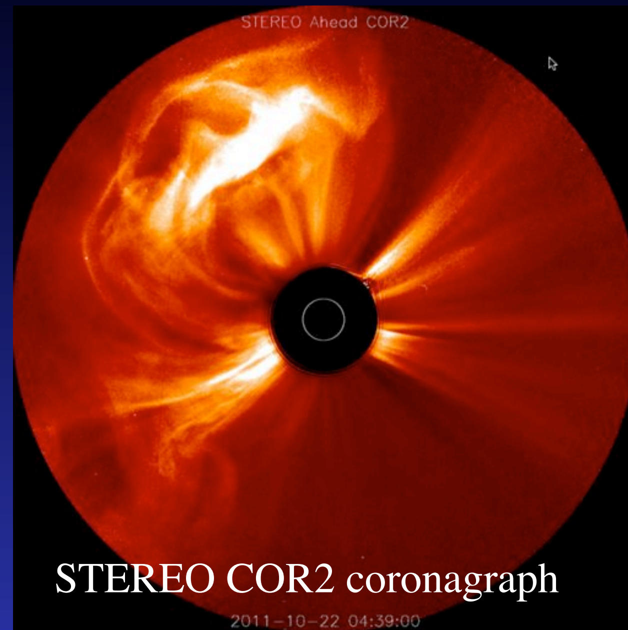
Act 1
Scene 3

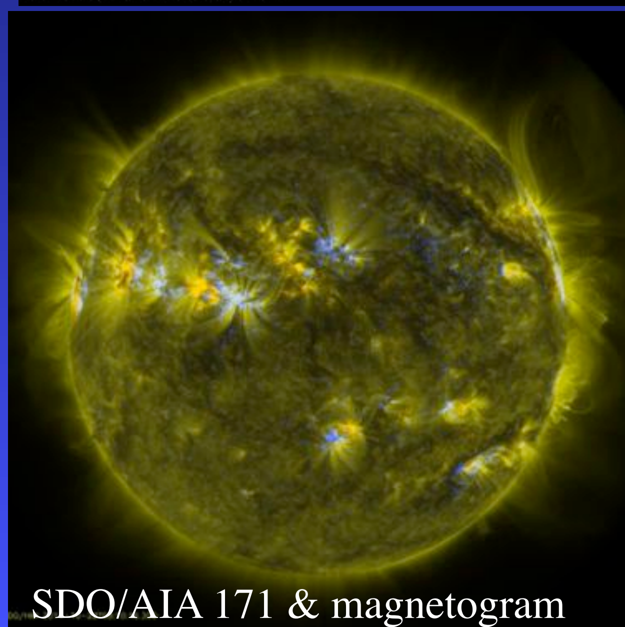
Back at the Sun

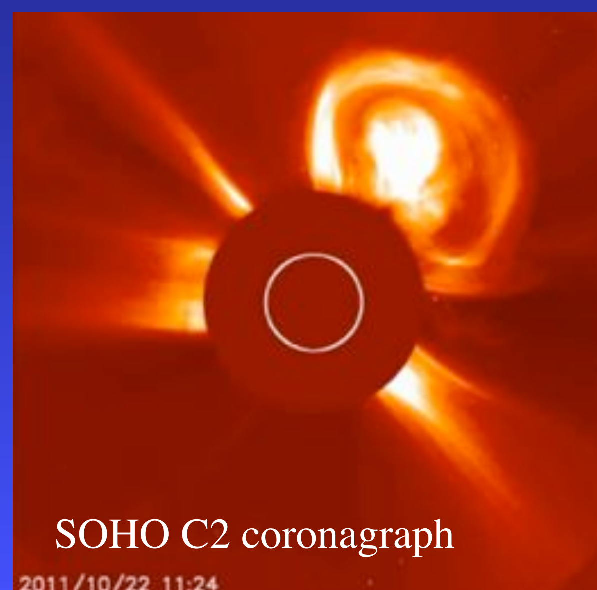
~2 days earlier

Back at the Sun: October 22, 2011



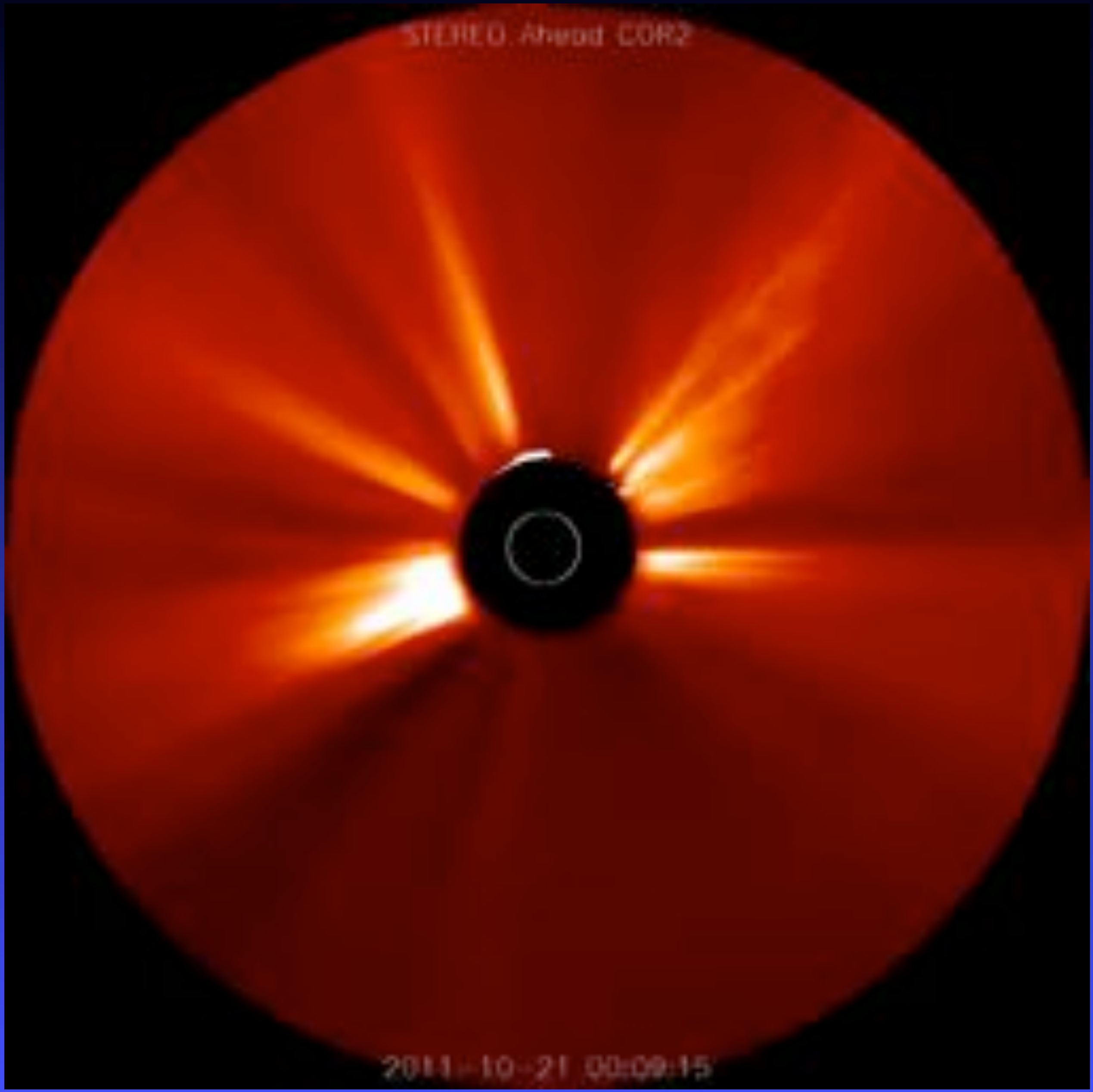






Back at the Sun: October 21-22, 2011

Coronal mass ejection viewed from STEREO ahead spacecraft



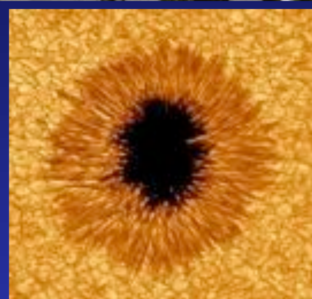
http://sohowww.nascom.nasa.gov/pickoftheweek/old/28oct2011/

Interlude:
Our Eyes on the Sun

Ground-based solar telescopes

McMath, Kitt Peak AZ

Big Bear, CA

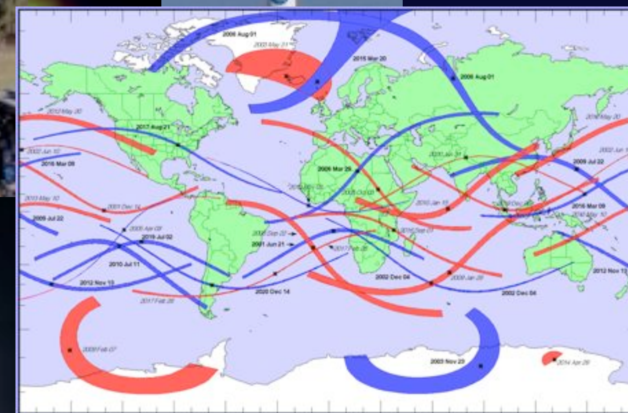


Solar Dynamics Observatory

spheric

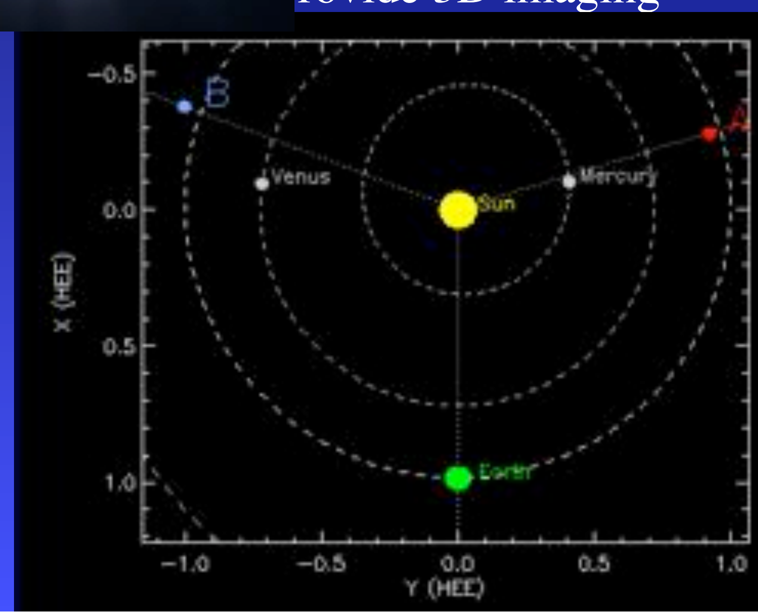
SOHO) 1995

Solar eclipse observations

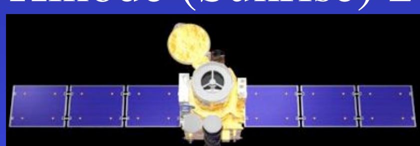


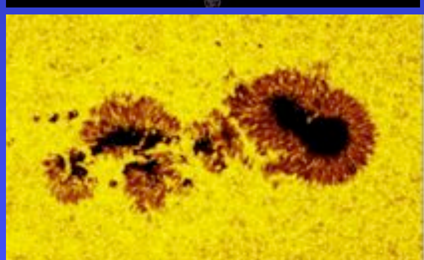
06

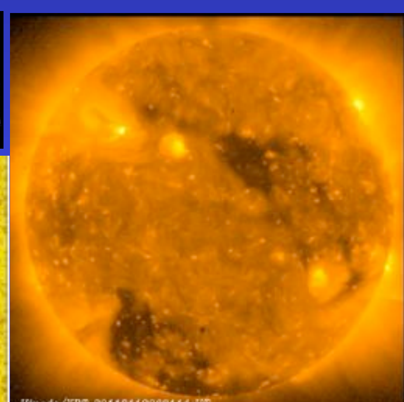
rovide 3D imaging



Hinode (Sunrise) 2006





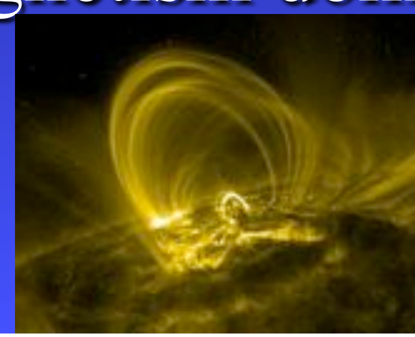


Act 2:
A Tale of Two Atmospheres

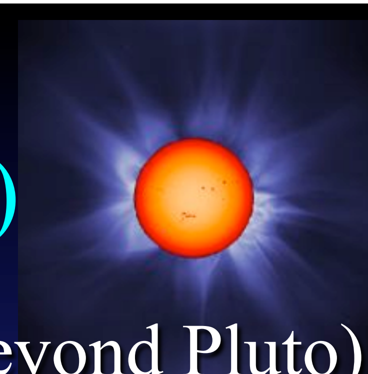
Two Atmospheres

Earth

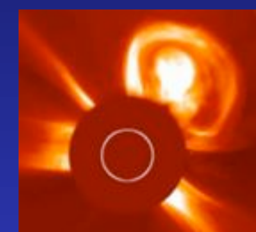
- Thin (~100 miles)



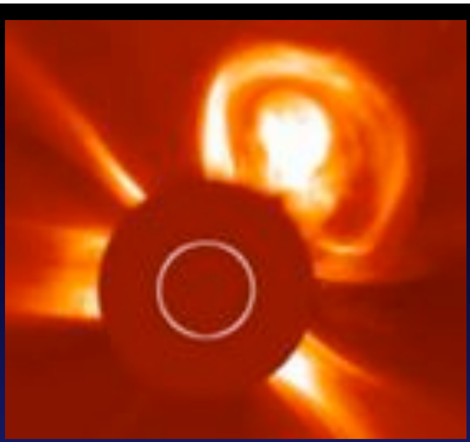
Sun (corona)



- Extended (beyond Pluto)
- ot (~2 million kelvin)
- iffuse
- indy
- arge storms
- ectrical conductor
- agnetism dominant



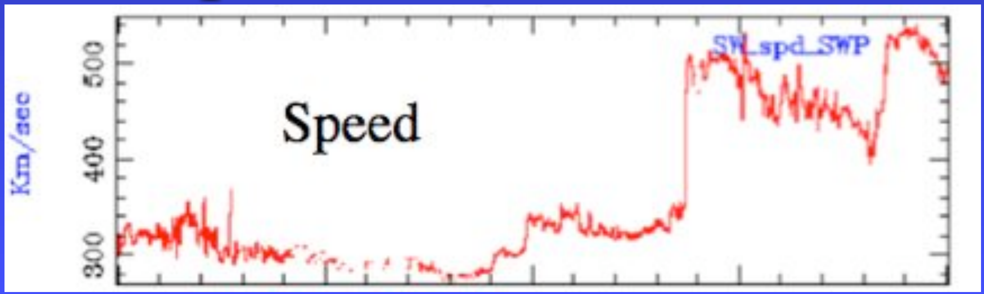
Coronal Mass Ejections: The Big Solar Storms



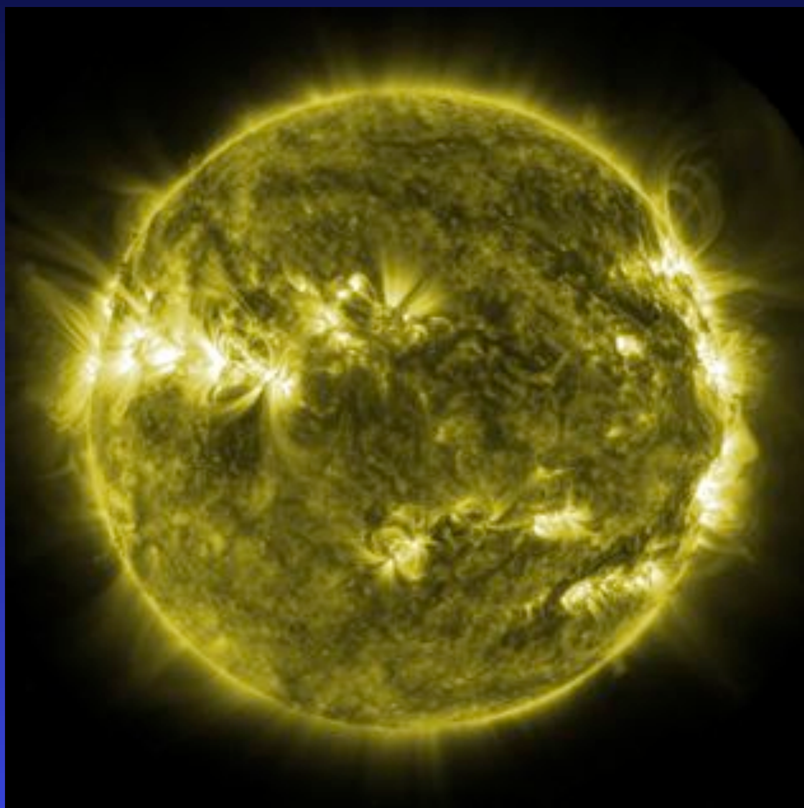
- Most energetic events in our Solar System
  - ~10 trillion nuclear bombs

- Eject 10 trillion tons of solar material into space

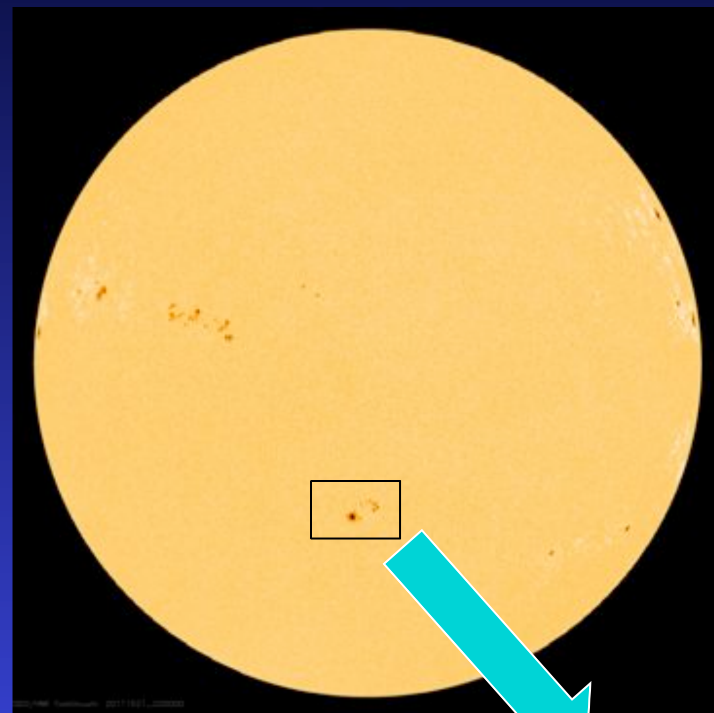
  - ~mass of a mountain
- Speeds up to 1000 miles/second



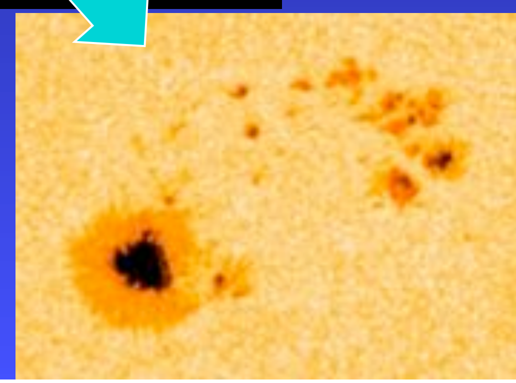
What Drives CMEs?
Magnetic Energy



SDO AIA 171 October 21, 2011

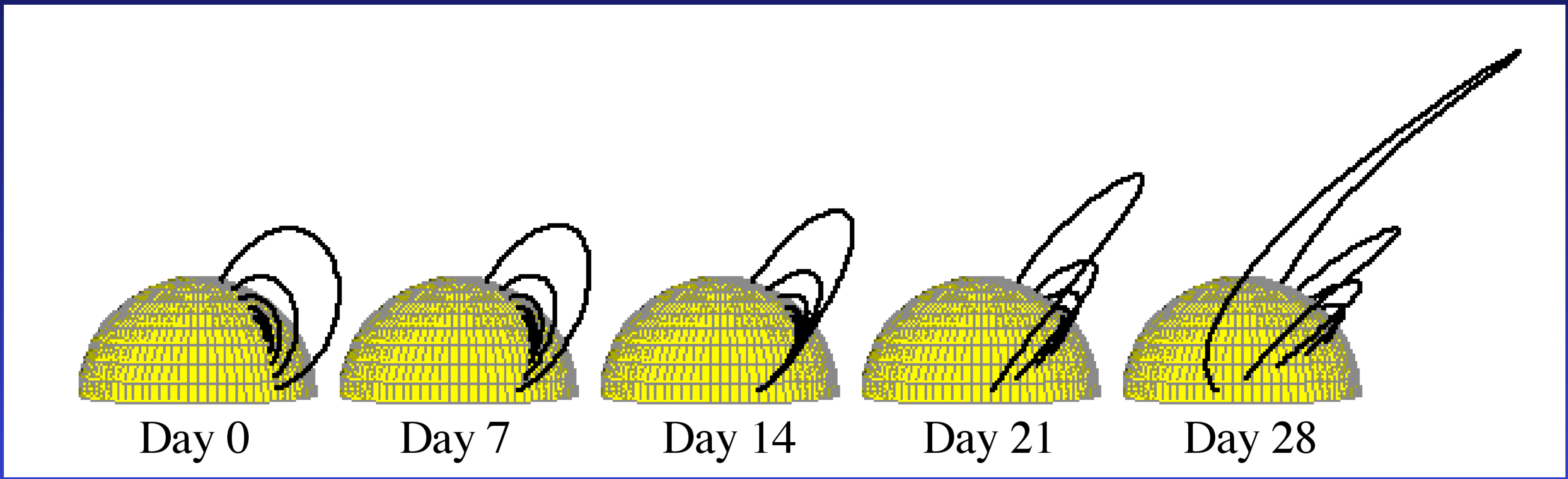


SDO HMI
October 21, 2011



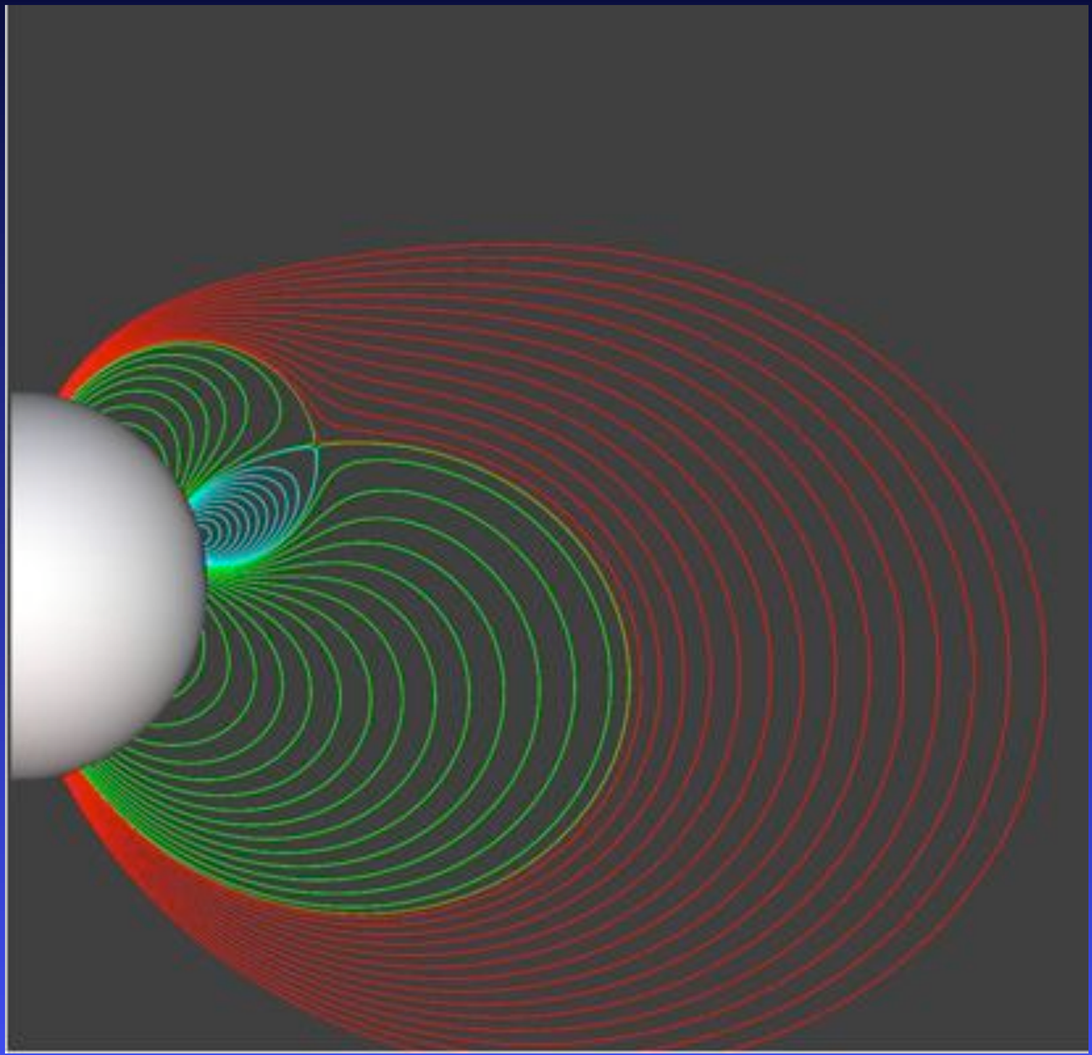
Building Up Magnetic Energy

Response of the magnetic field to the Sun's differential rotation



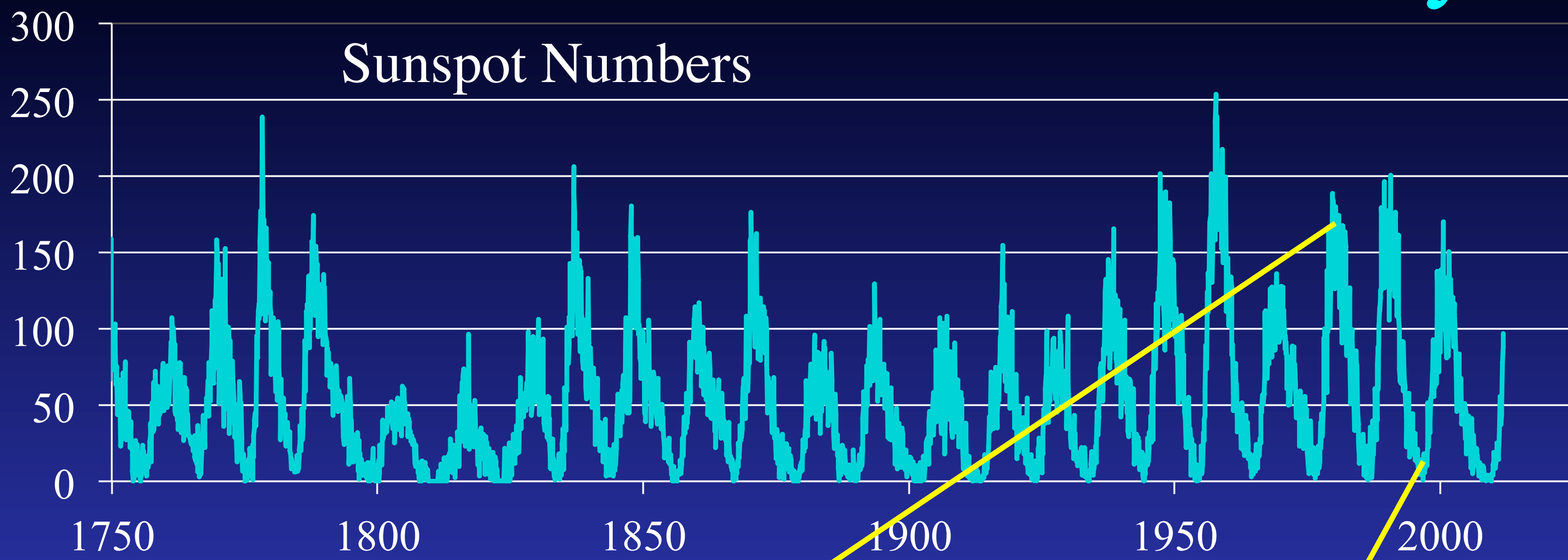
Wolfson et al. *ApJ* 463, 369 1996

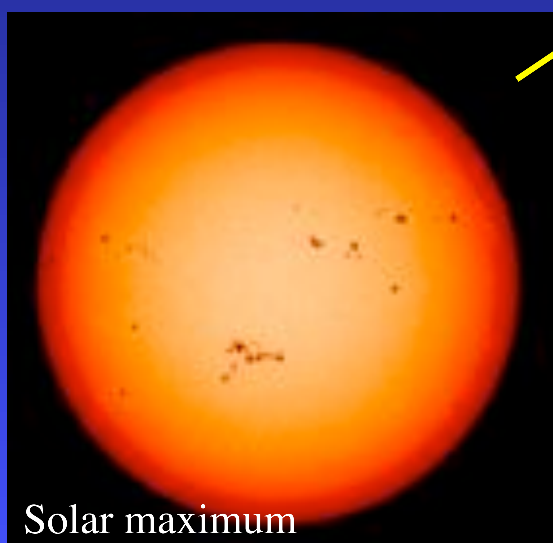
Simulating a Solar Storm



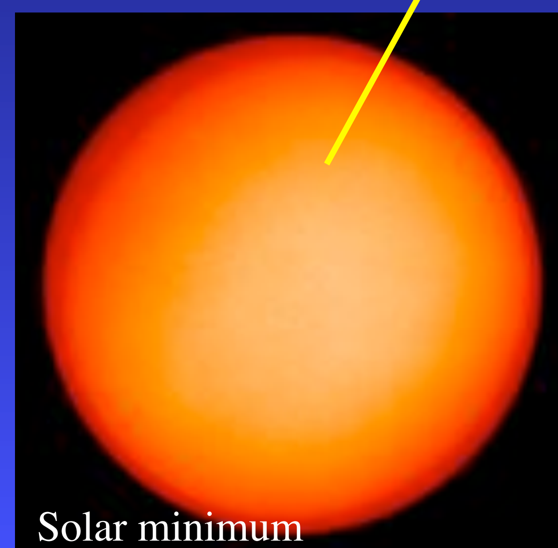
Simulation by Ben Lynch, Space Sciences Lab, UC Berkeley: http://sprg.ssl.berkeley.edu/~blynch/

Seasons on the Sun: The Solar Cycle

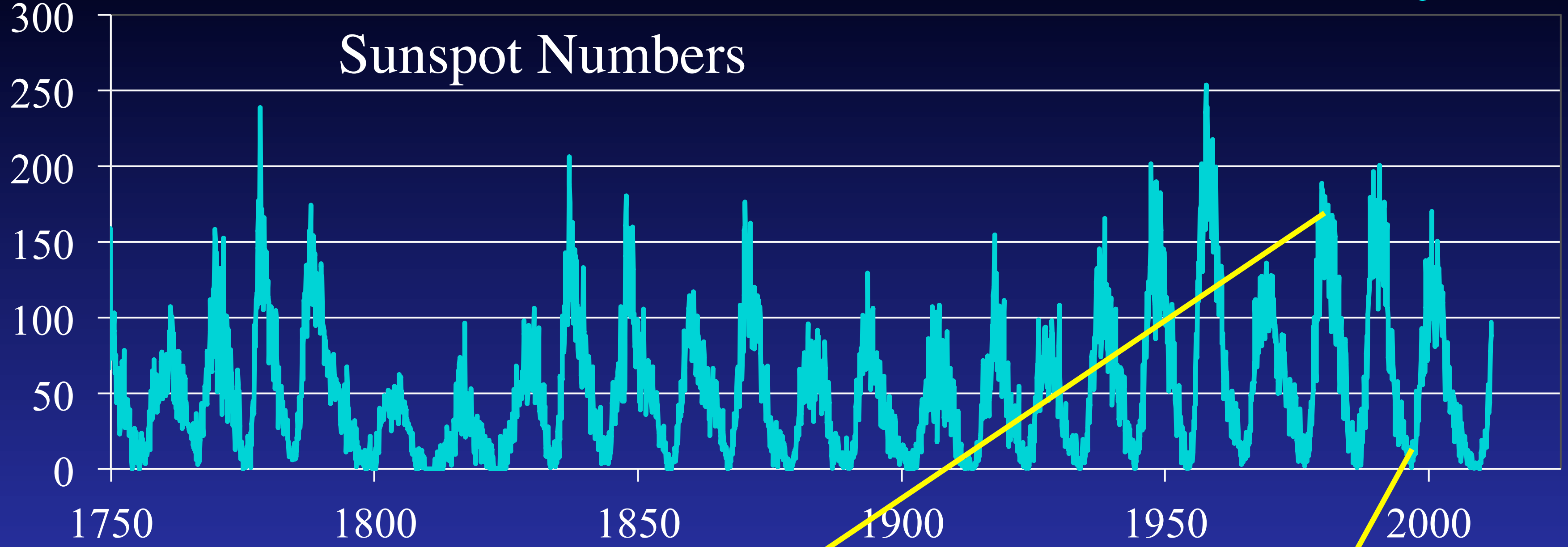




Solar Surface



Seasons on the Sun: The Solar Cycle



Eclipse Photos

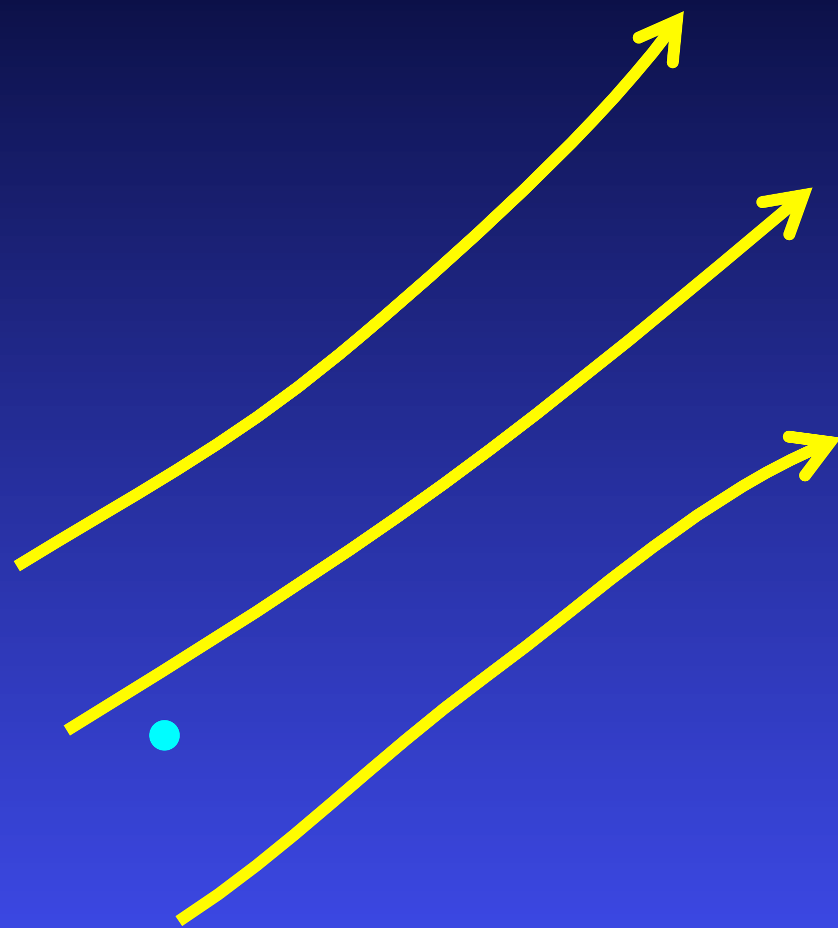

1980 February 16 Palem, India


1995 October 24 Dundlod, India

Act 3:
Sun-Earth Connection

A Short Physics Lesson: Charged Particles and Magnetic Fields

- Charged particles move easily *along* magnetic fields
- It's difficult for them to move *perpendicular* to magnetic fields
- Consequence: they trace out spiral paths in magnetic fields



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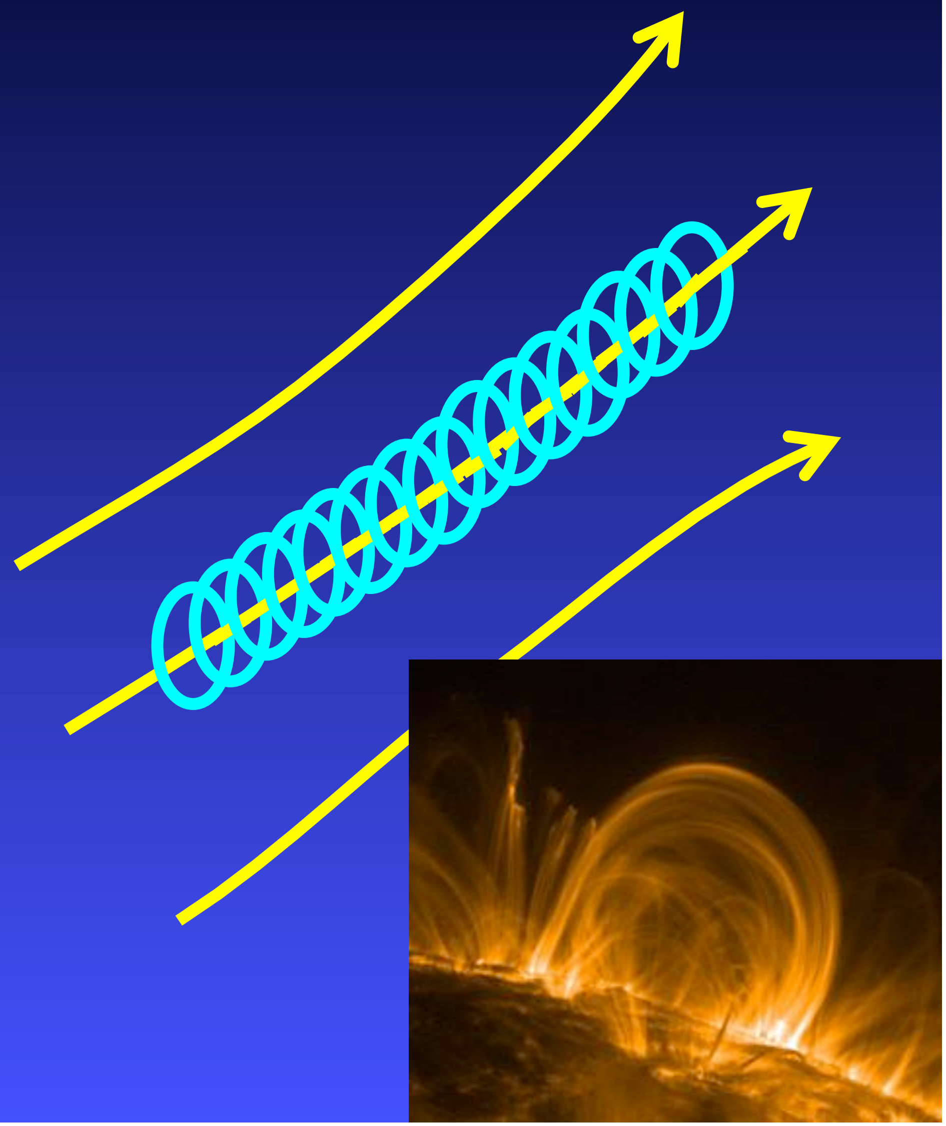
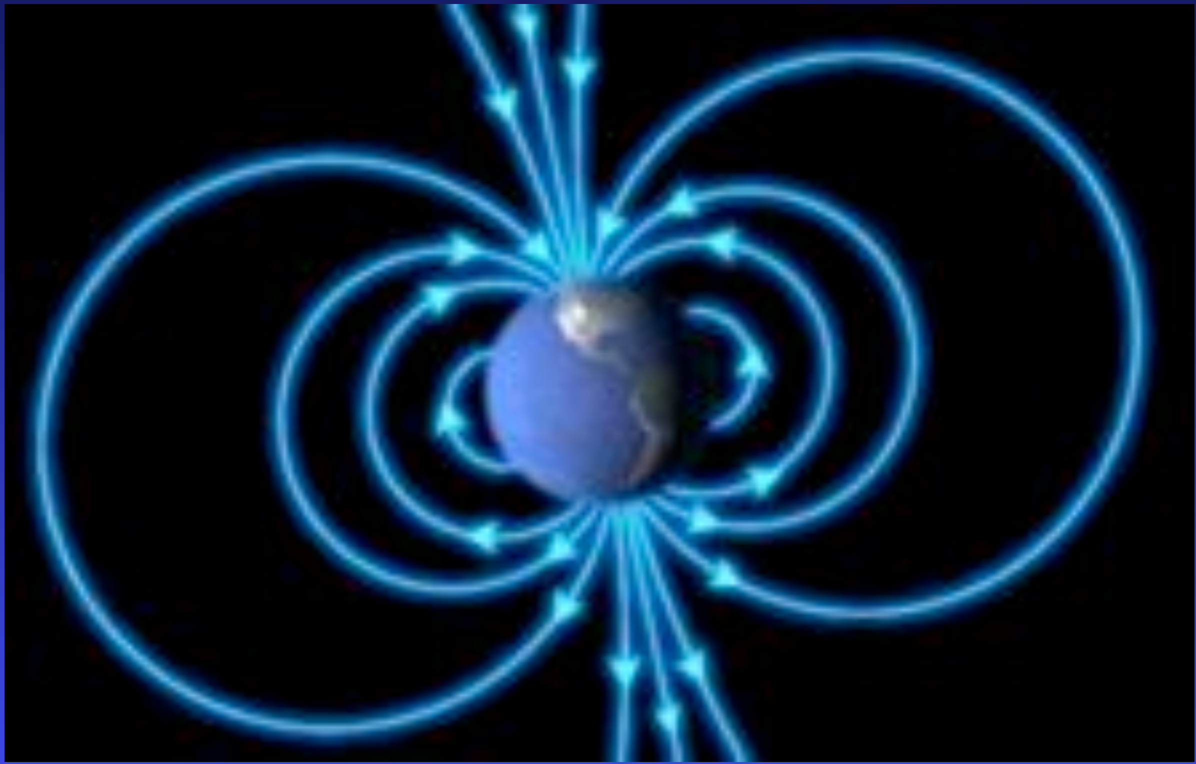
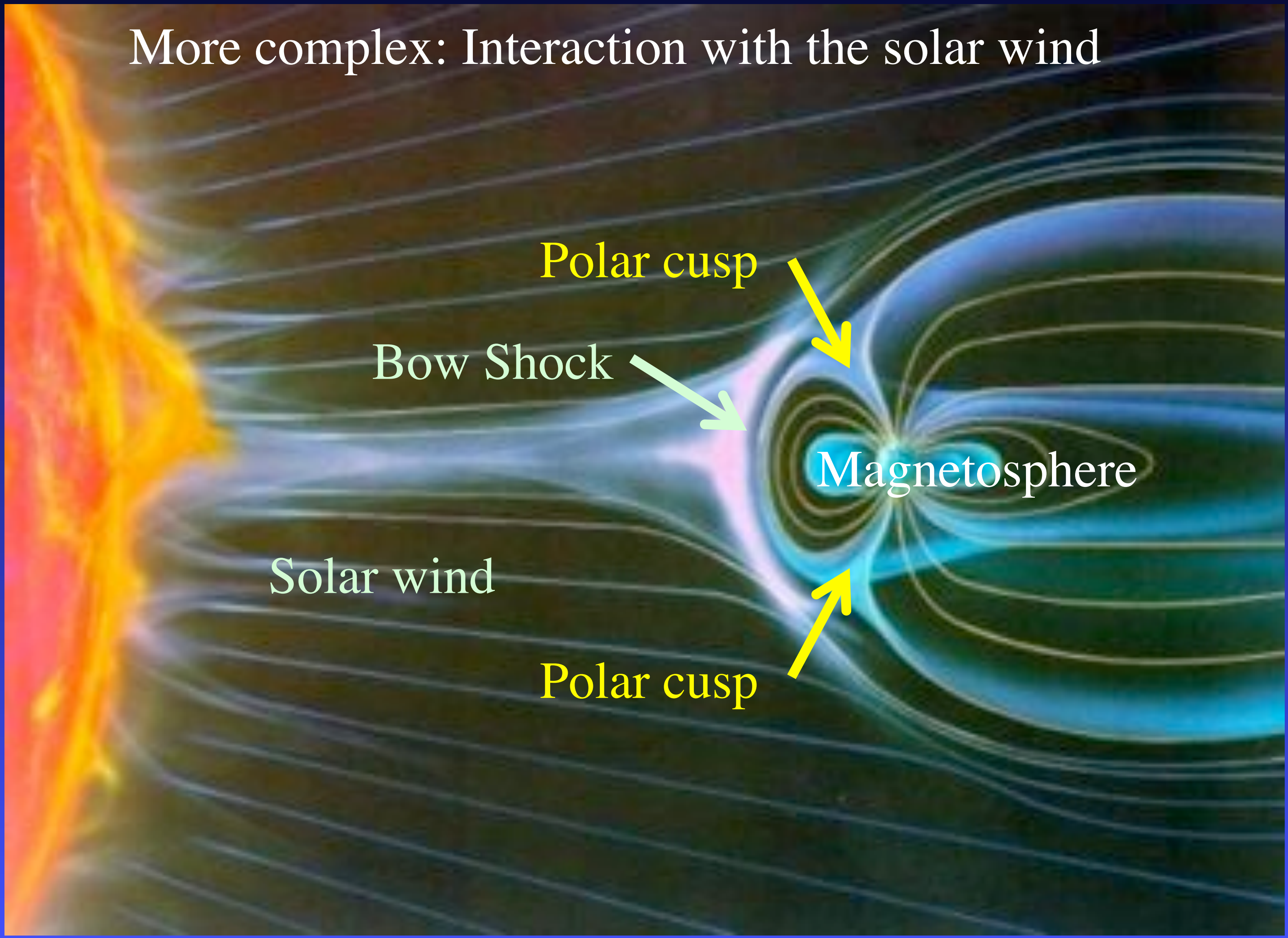


Earth’s Magnetic Field

Simple view: Earth in isolation

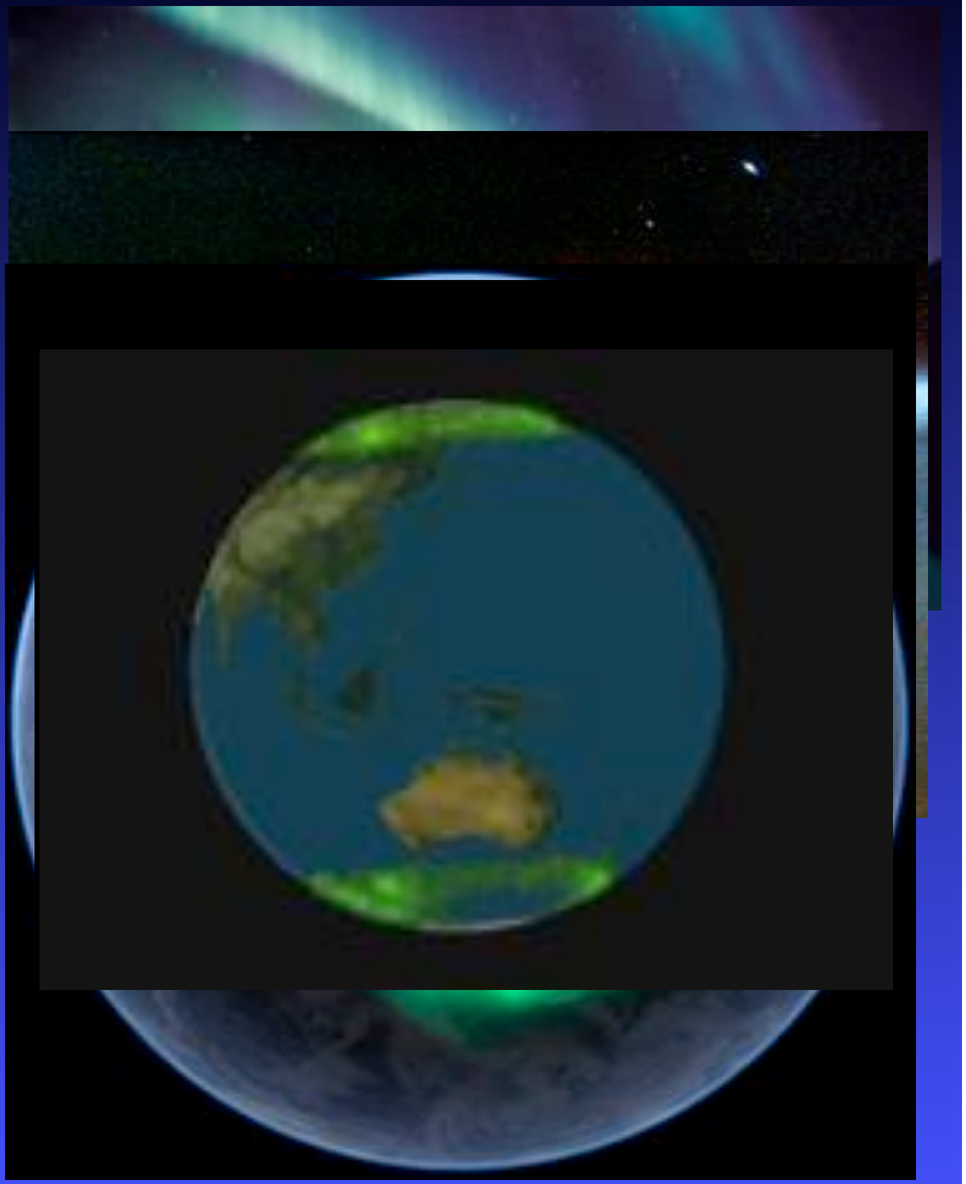


Earth's Magnetic Field



Auroras

- Result from high-energy solar particles penetrating the polar cusps
- Particles excite oxygen & nitrogen atoms in upper atmosphere
  - Atoms de-excite, emitting light
- Particles "mirror" back and forth between northern and southern hemispheres



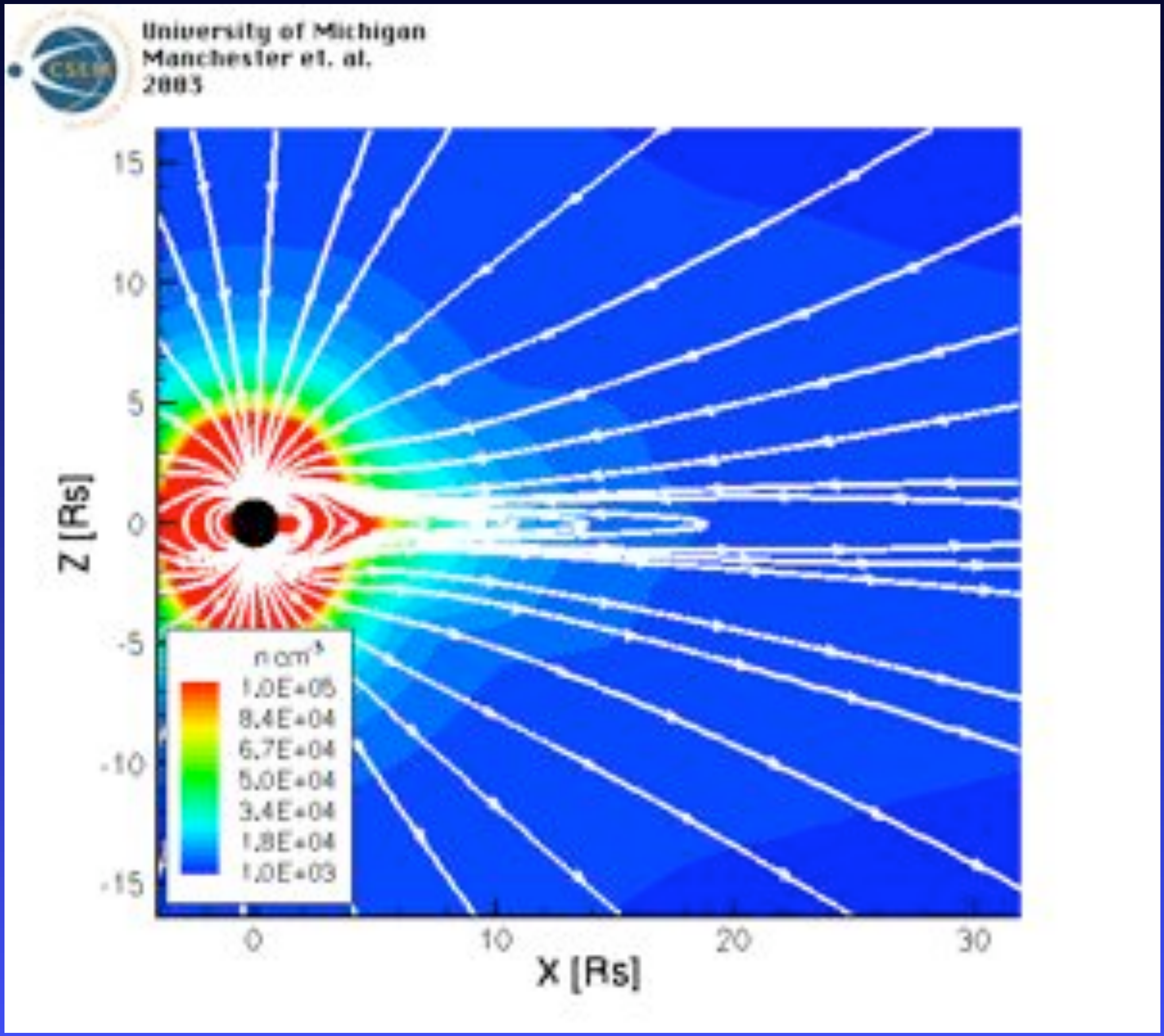
Another Physics Lesson

- Changing magnetic fields induce electric currents
  - Basis of electric generators
  - Basis of geomagnetic storms

Simulating a CME: Sun to Earth

Another Strong Magnetic Storm Pummels Earth
Los Angeles Times 10/31/03

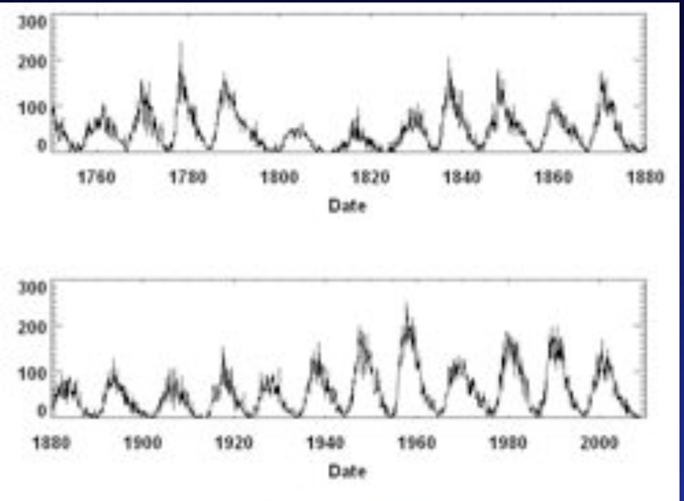
Flare Damages Mars Odyssey Probe
BBC News 11/28/03



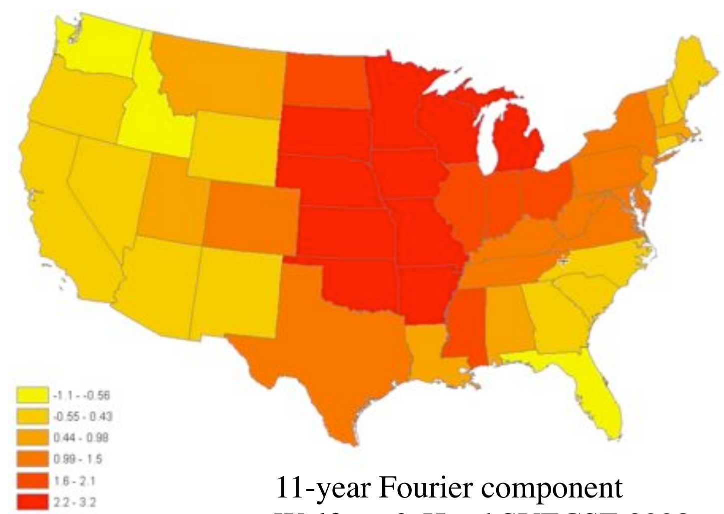
Courtesy of Ward Manchester, University of Michigan

The Sun and Climate

- Connection usually overblown!
- Weak solar-cycle signal present in climate records
- Total solar luminosity variation over solar cycle: ~ 1 W/m^2; ~0.1%
- Resulting temperature variation: ~several hundredths of a degree
- BUT:
  - UV variation much greater
  - Forcing change in rising cycle comparable to CO_2 increase

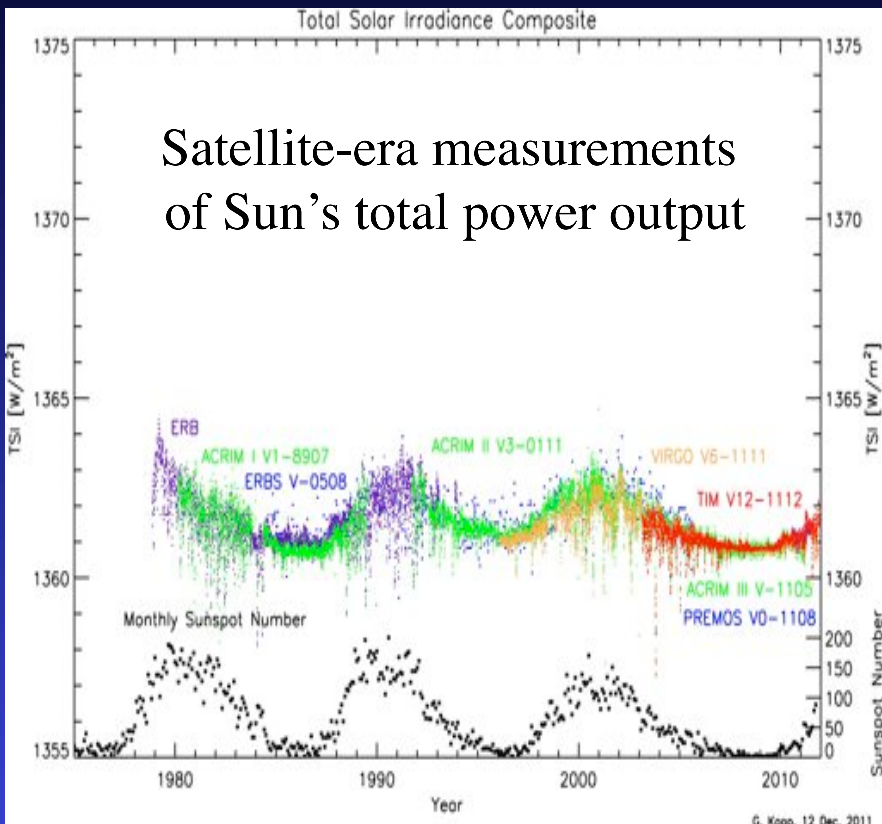


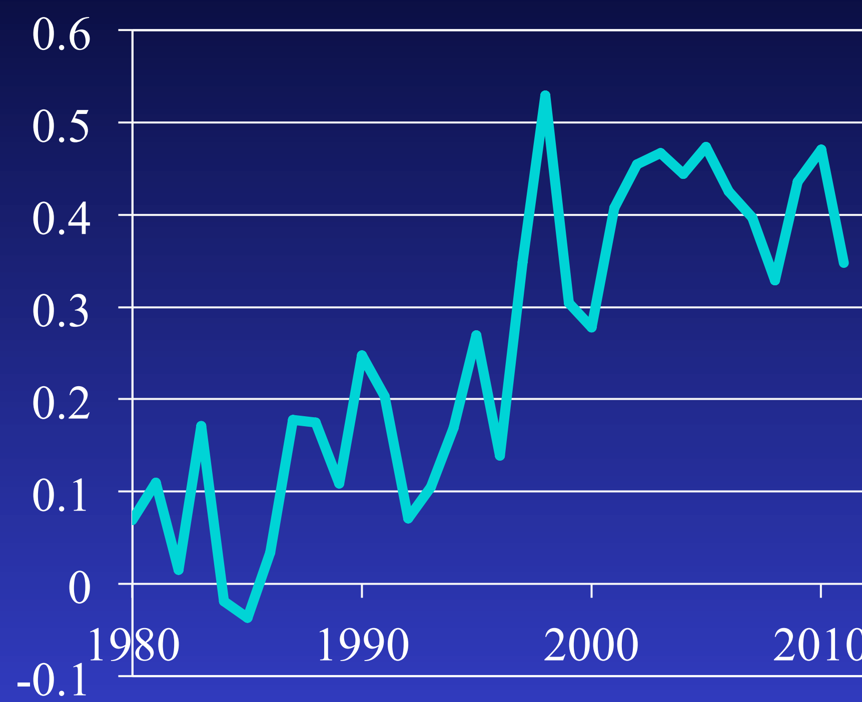
Zurich sunspot numbers



11-year Fourier component
Wolfson & Hand SVECSE 2008

Longer Term Effects? (~30 years)



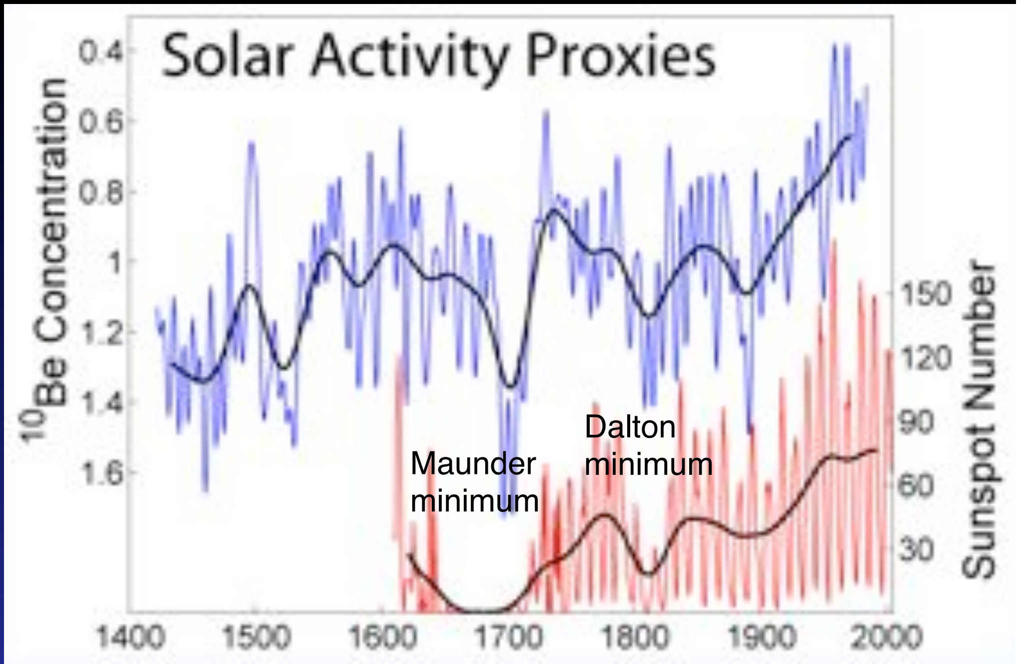


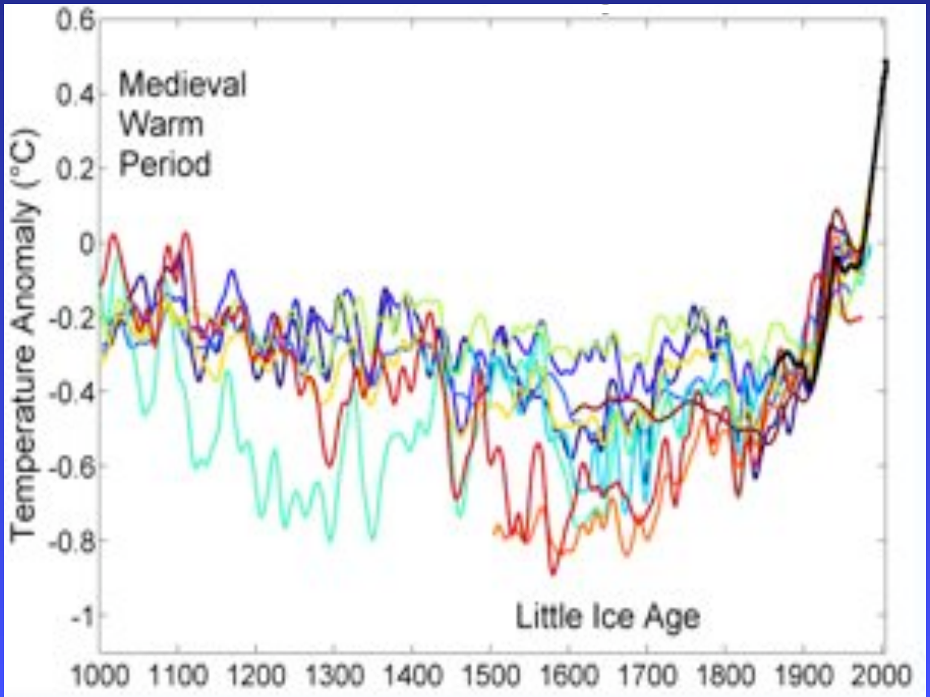
Global temperature, ˚C

(deviation from 1961-1990 average)

Climatic Research Unit, UEA

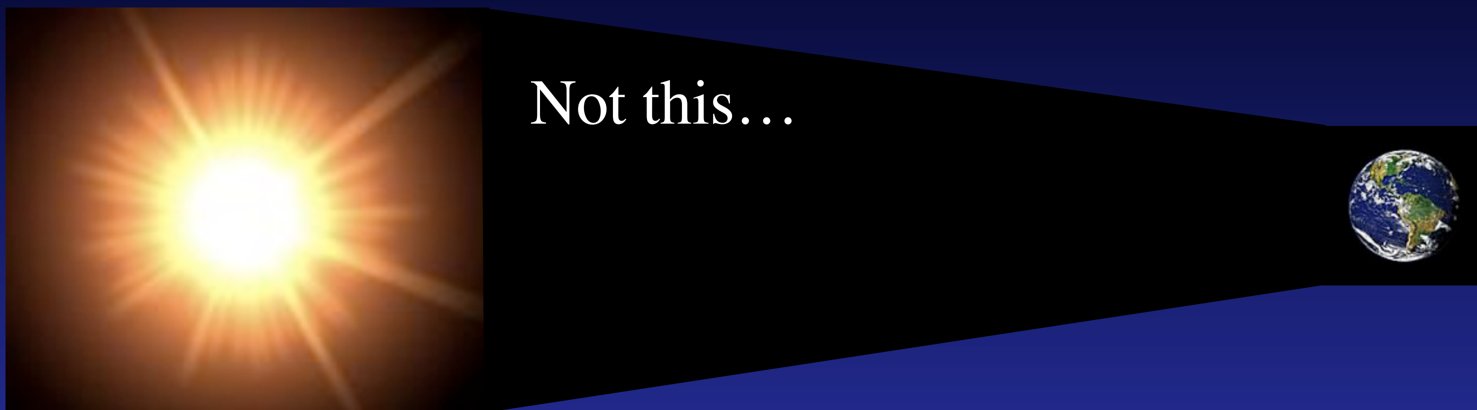
Millennial effects?





Proxy-based millennial temperature reconstructions

Final Scene: Sun and Earth



…but this