

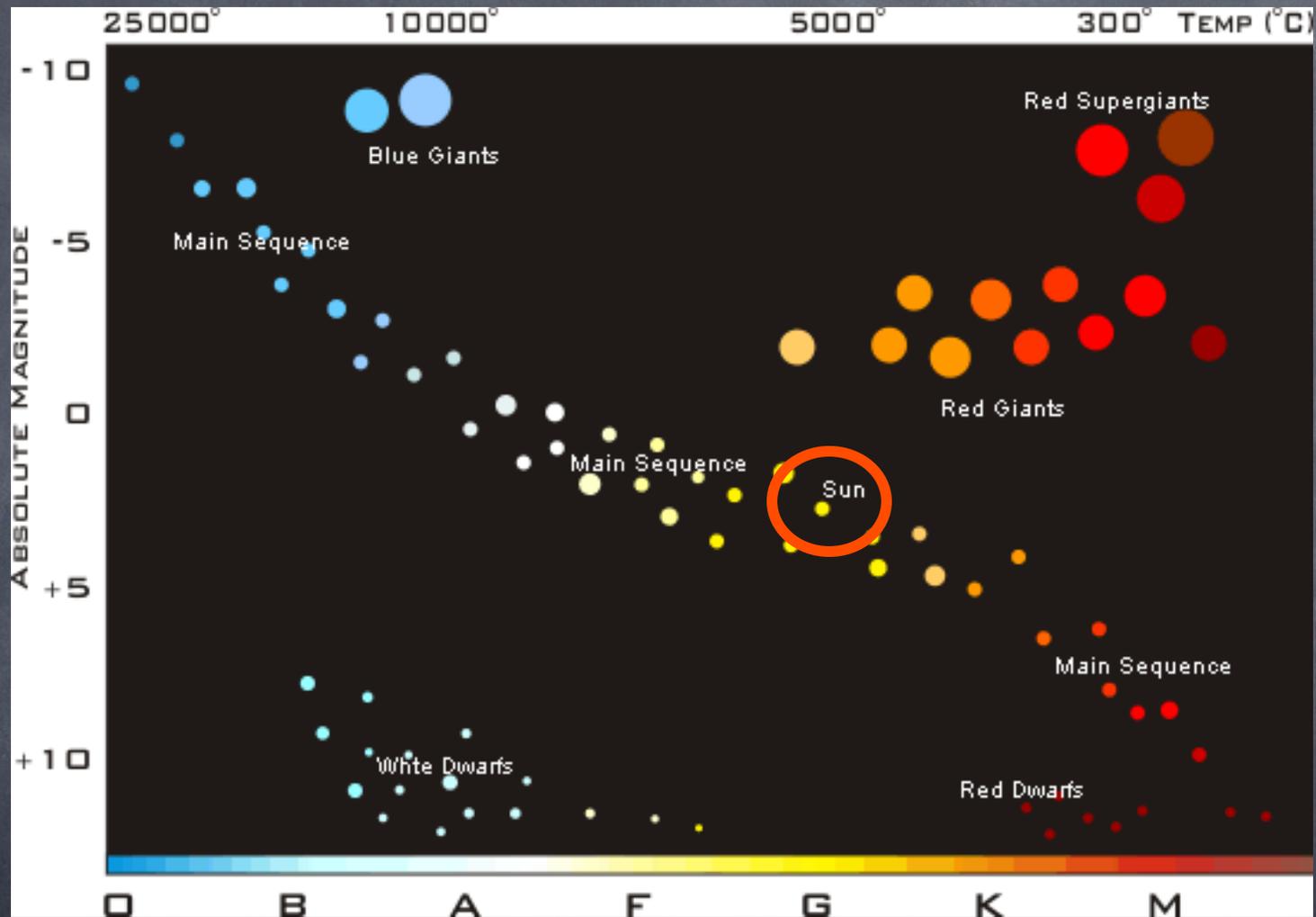
The Sun-Earth Connection: Solar Variability and Climate Change

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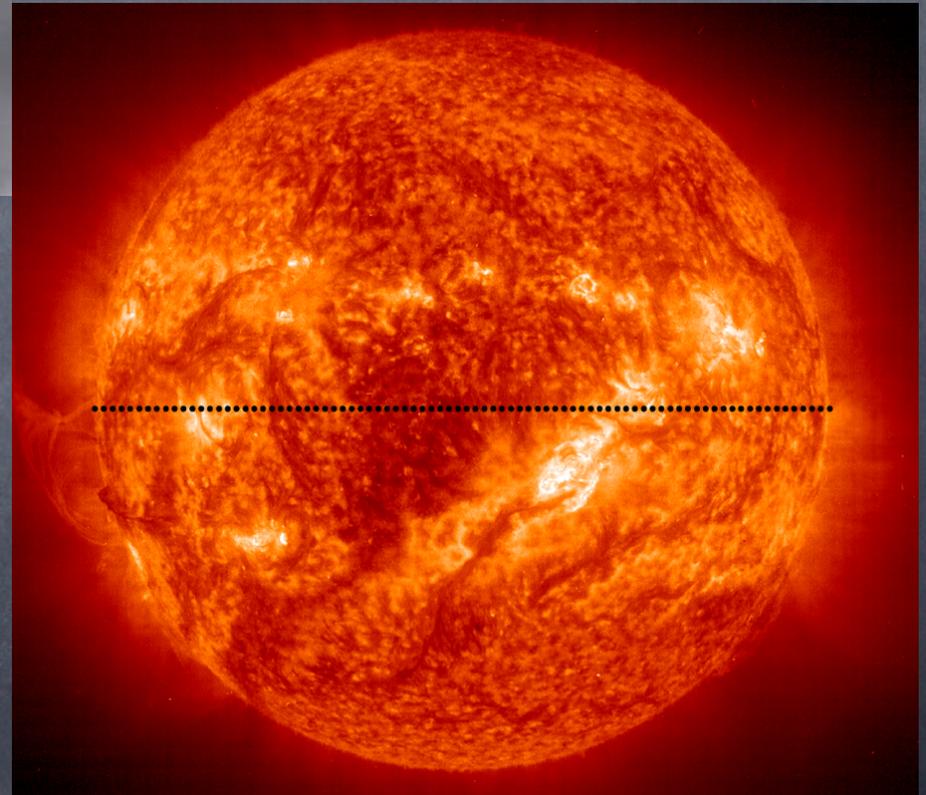
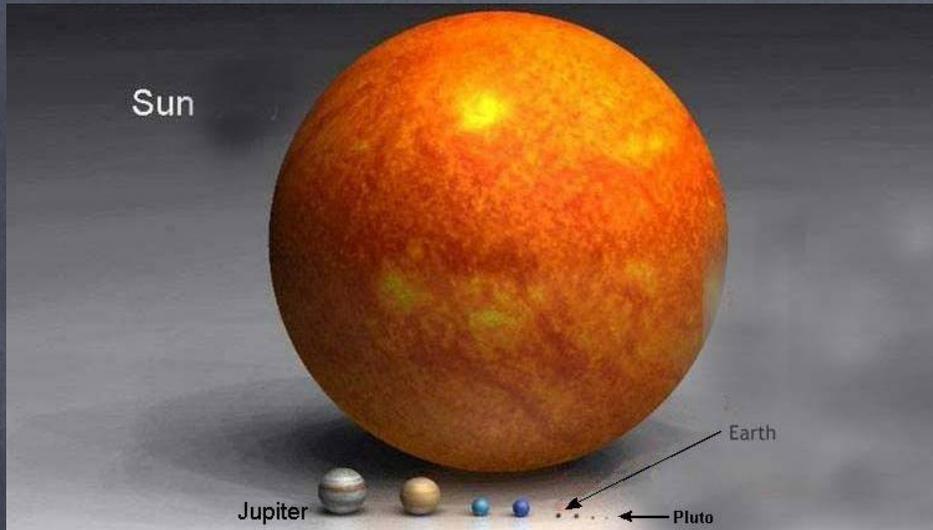
Outline

- The Sun:
 - Interior
 - Magnetic Field
 - Variability
- The Earth's Energy Budget
 - Albedo
 - Greenhouse Gases
 - Feedbacks

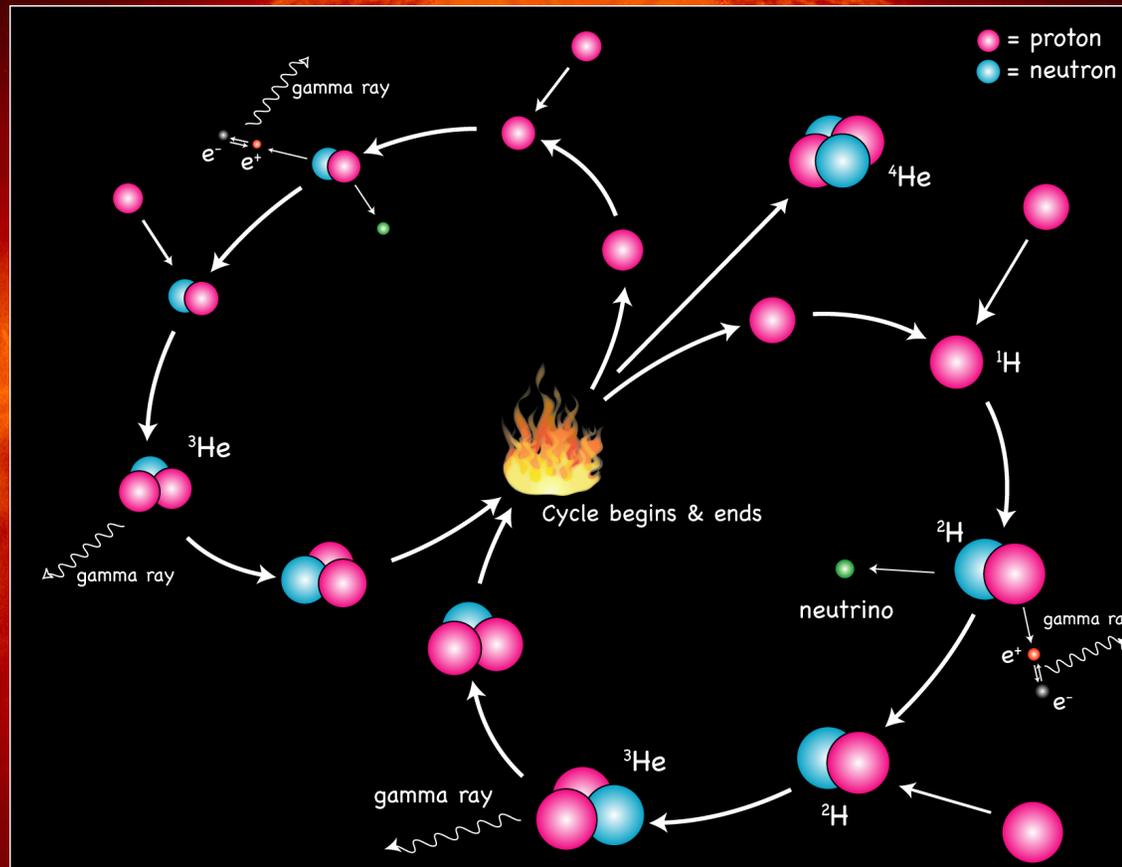
Herzsprung-Russel Diagram

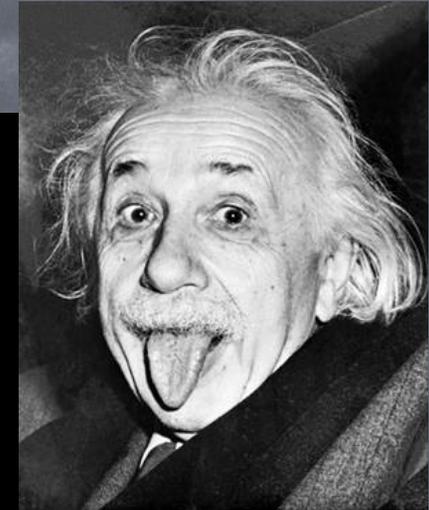
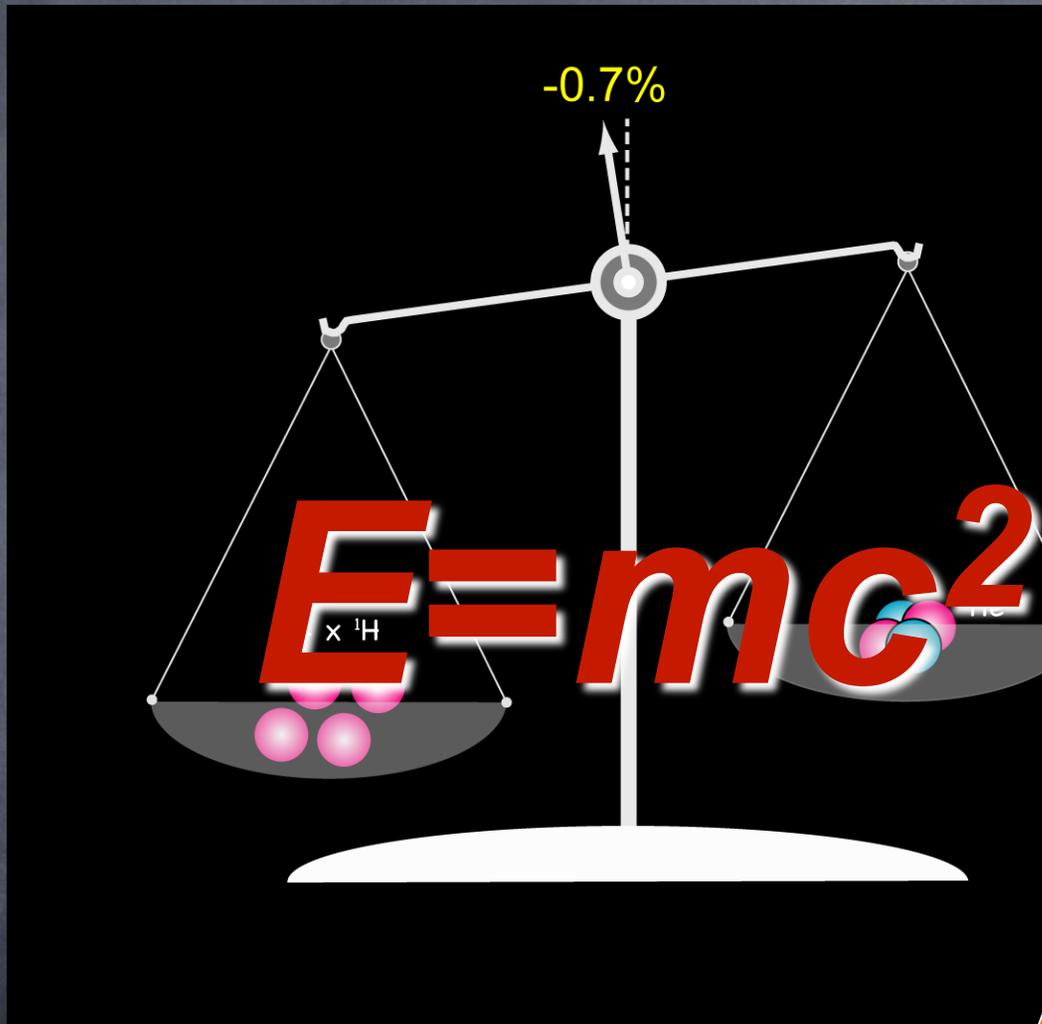


Size of the Sun



Hydrogen Fusion in the Sun "The Proton-Proton Chain"





$600 \times 10^9 \text{ kg H} \longrightarrow 596 \times 10^9 \text{ kg He}$

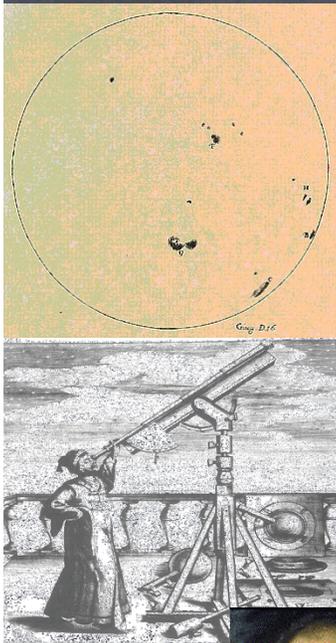
$4 \times 10^9 \text{ kg to Energy}$

Nuclear reactions in the core
burn steadily, but the surface
changes daily

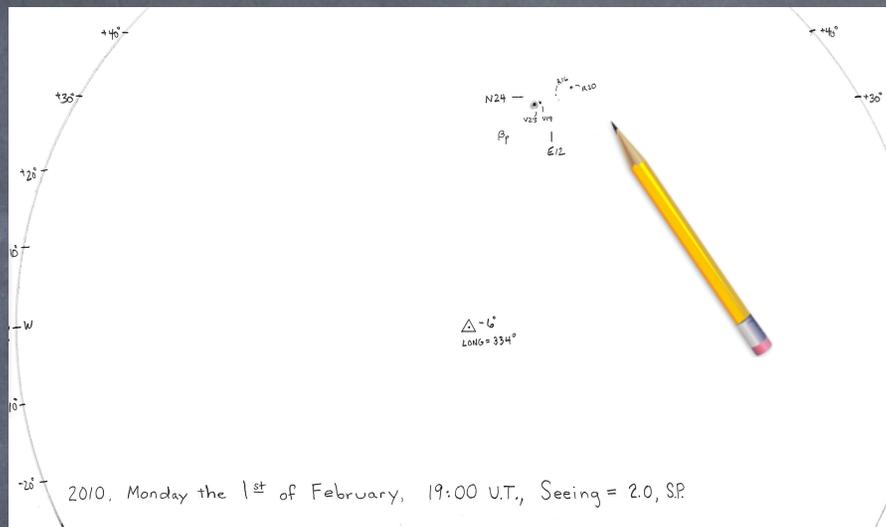


Sunspot record

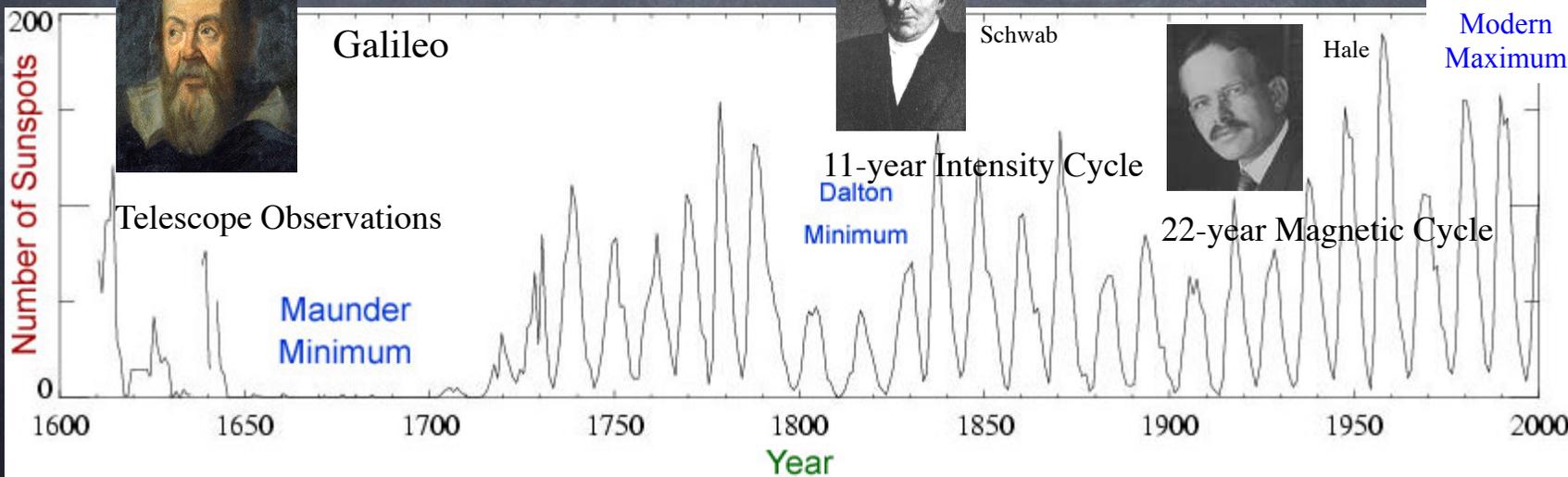
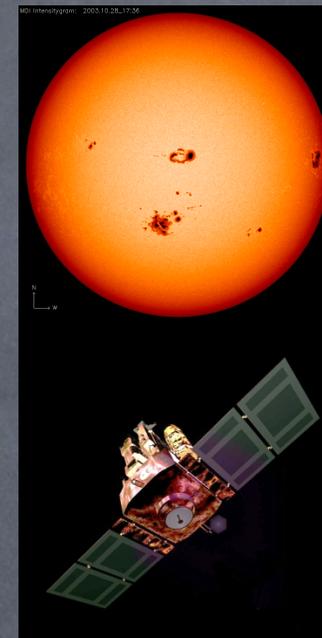
Galileo 1613



~400 years since 1610

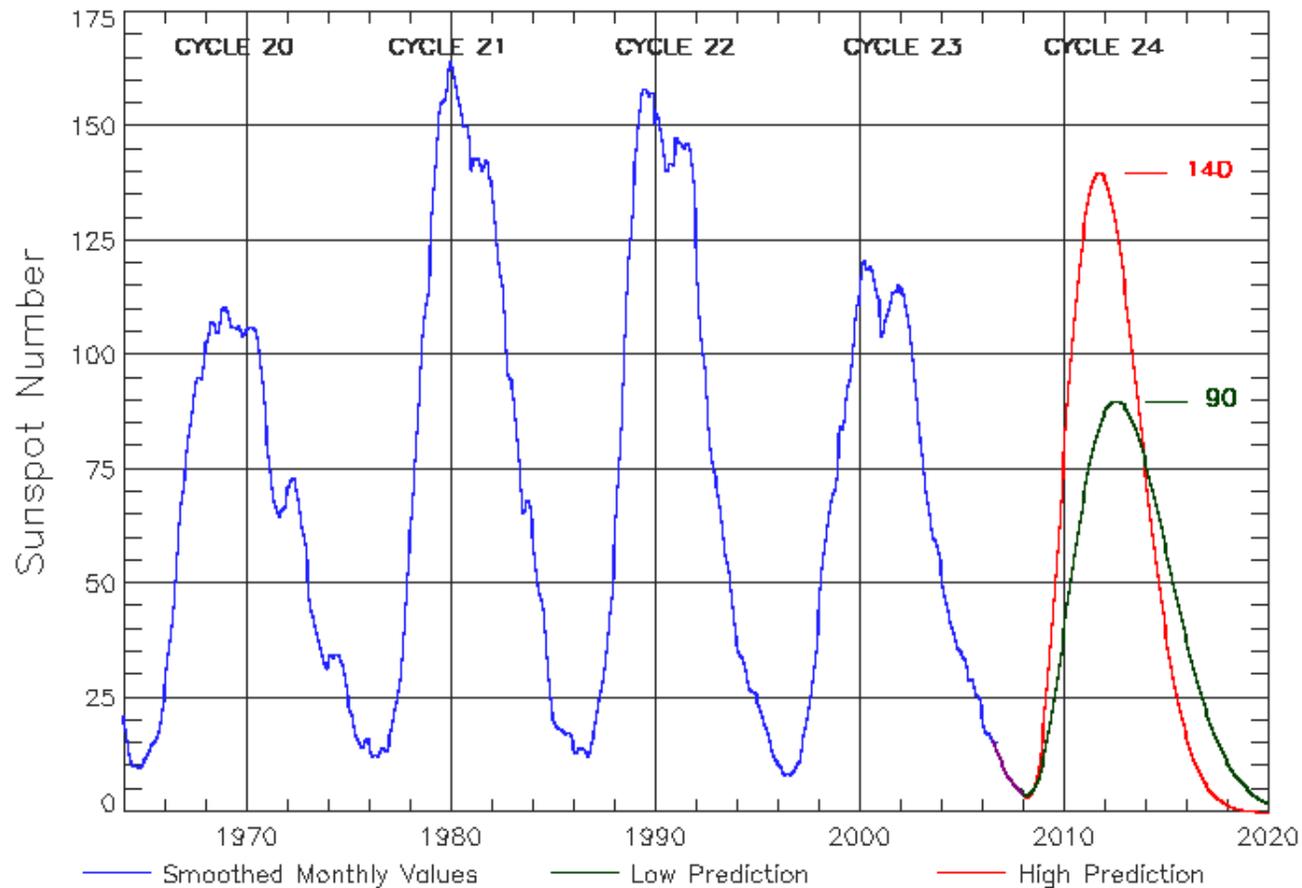


SOHO 2003



Prediction of Sunspots for the near future

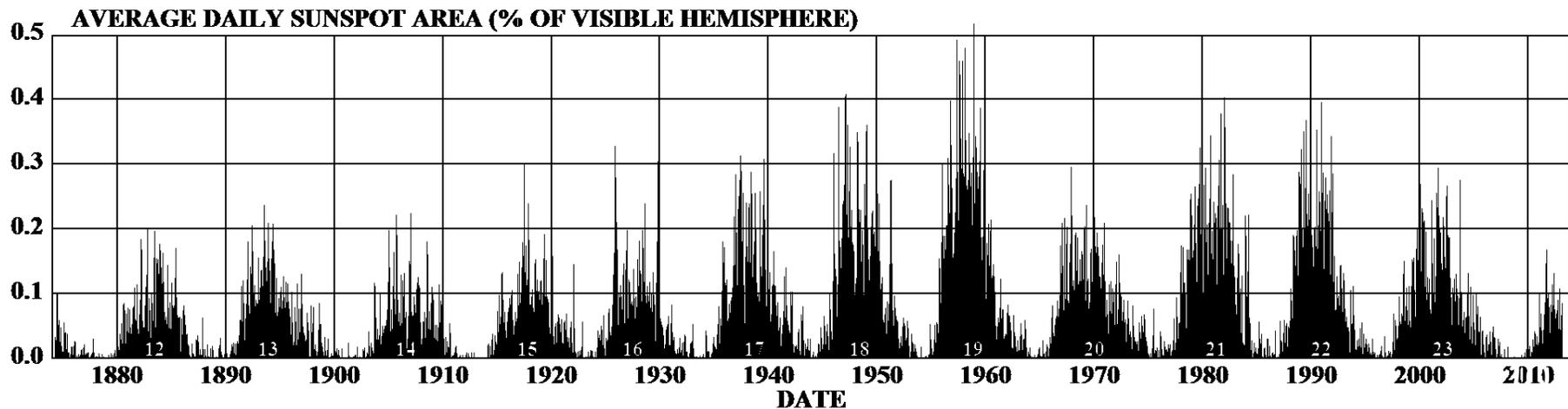
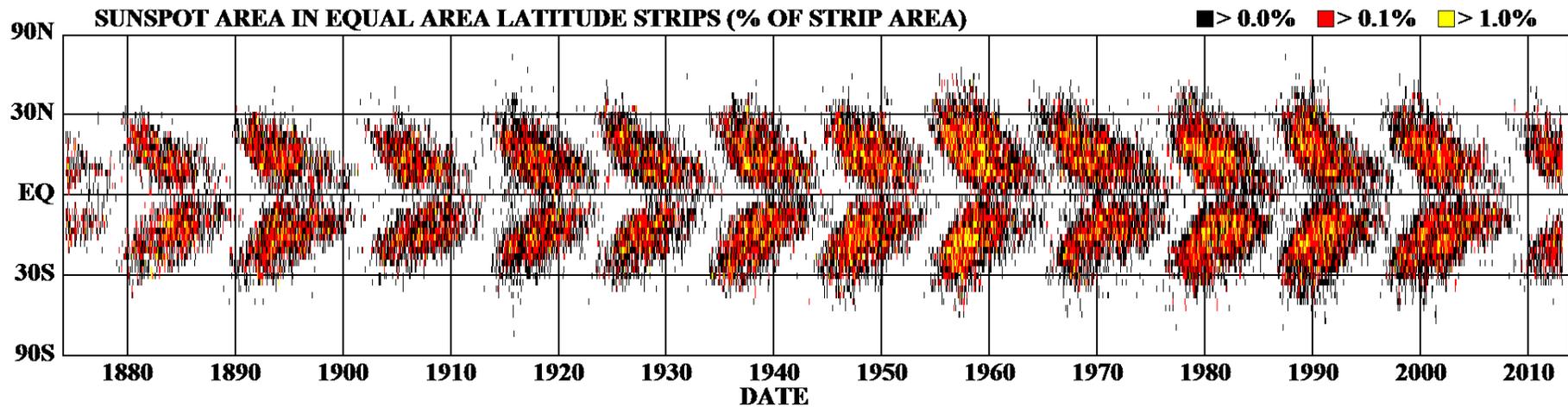
Solar Cycle 24 Sunspot Number Prediction



Sunspot Latitudes



DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

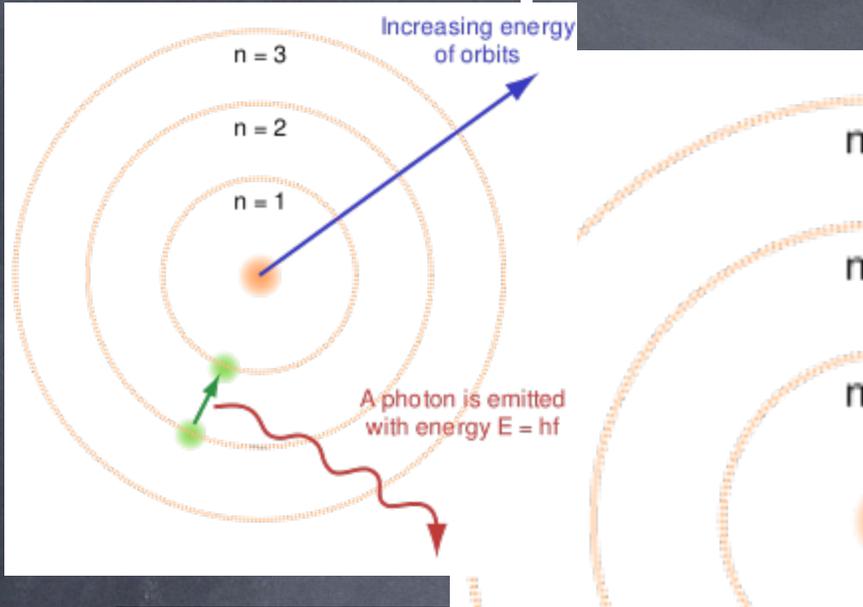


So what are these spots
anyway?

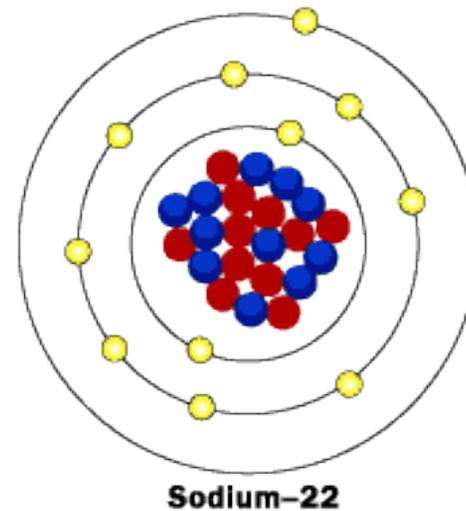
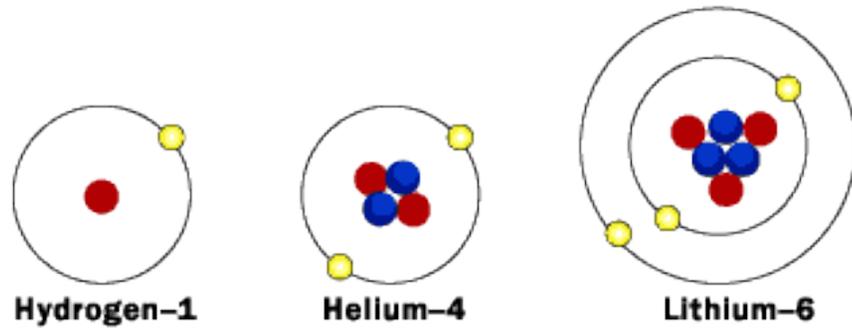
A brief detour into atomic physics...



Simple Model of Atom

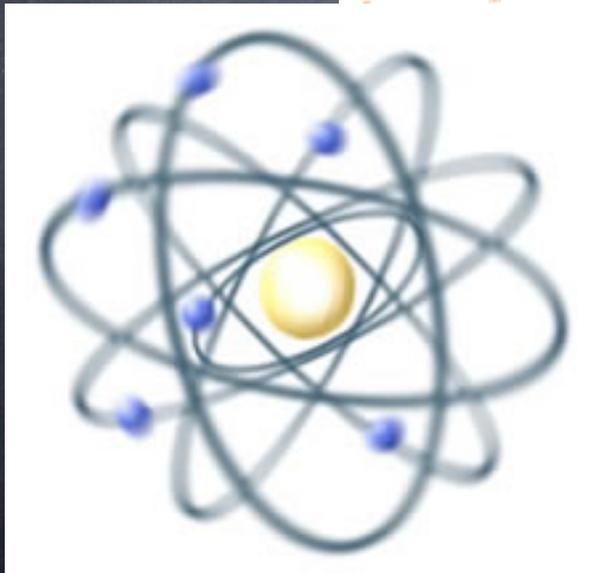


Isotopes of Hydrogen, Helium, Lithium and Sodium

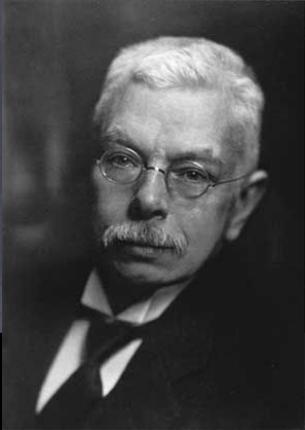


● Neutron ● Proton ● Electron

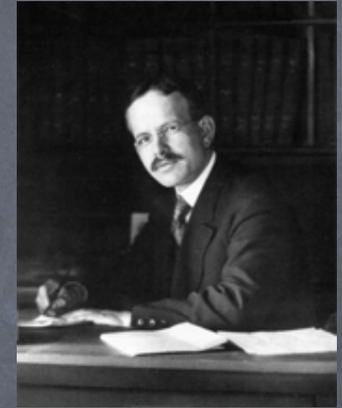
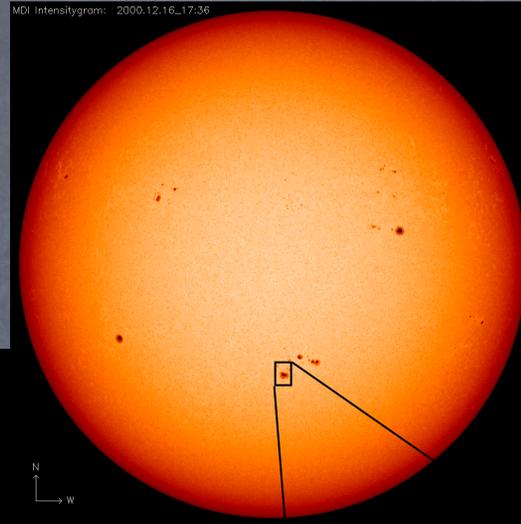
©2001 How Stuff Works



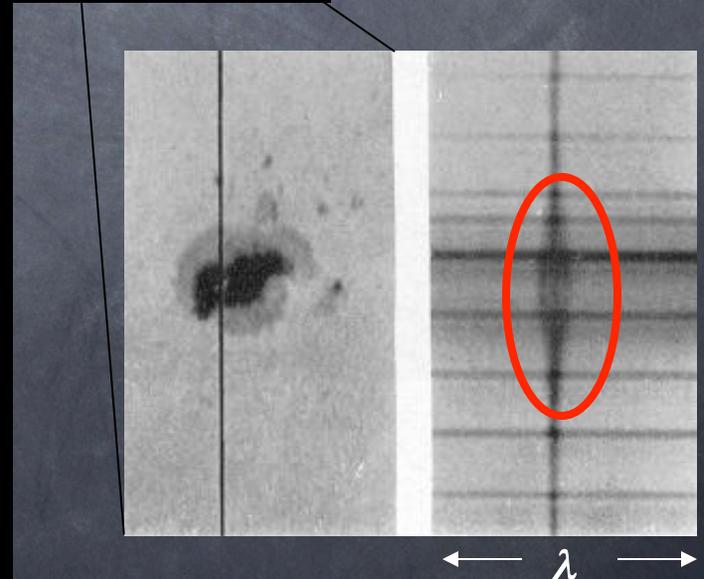
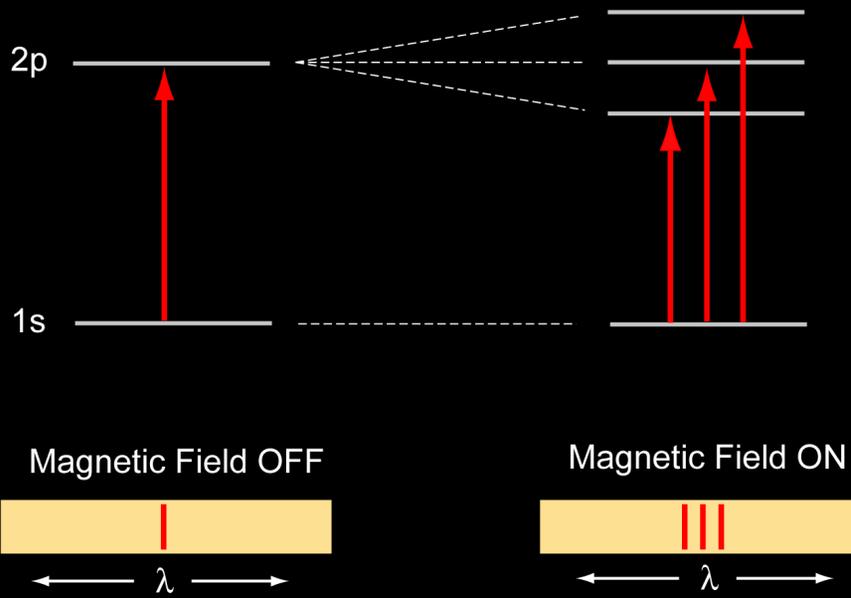
Magnetic Fields and Sunspots



P. Zeeman



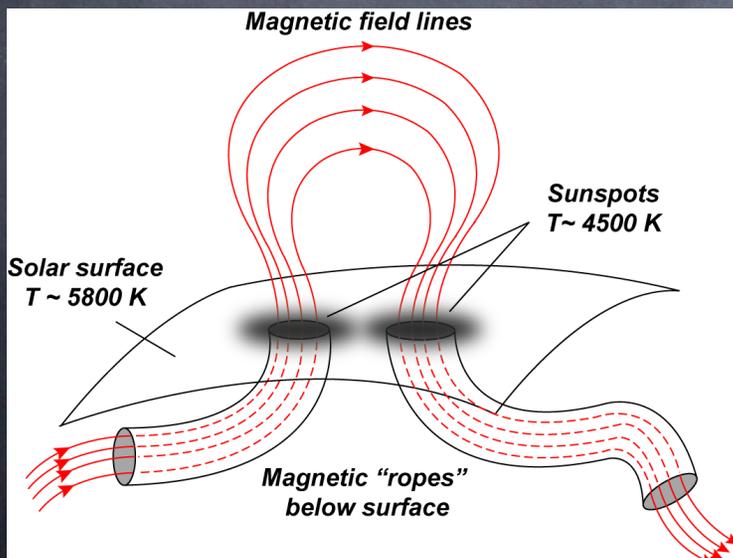
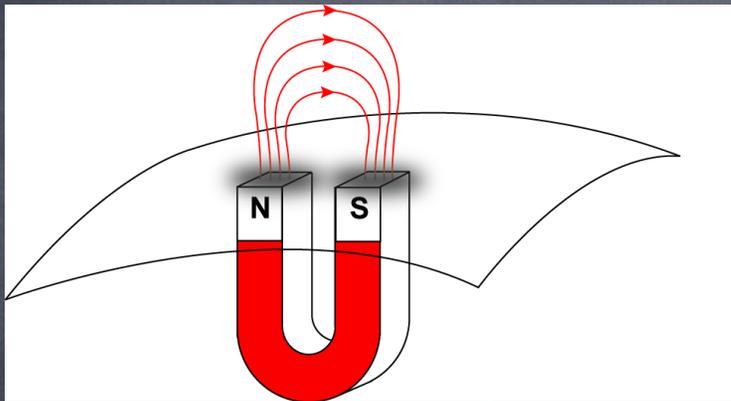
G. E. Hale



G.E. Hale, June 1908¹³

The formation of sunspots

Hale provided the first proof that sunspots are the seats of strong magnetic fields



High in the Sun's Atmosphere

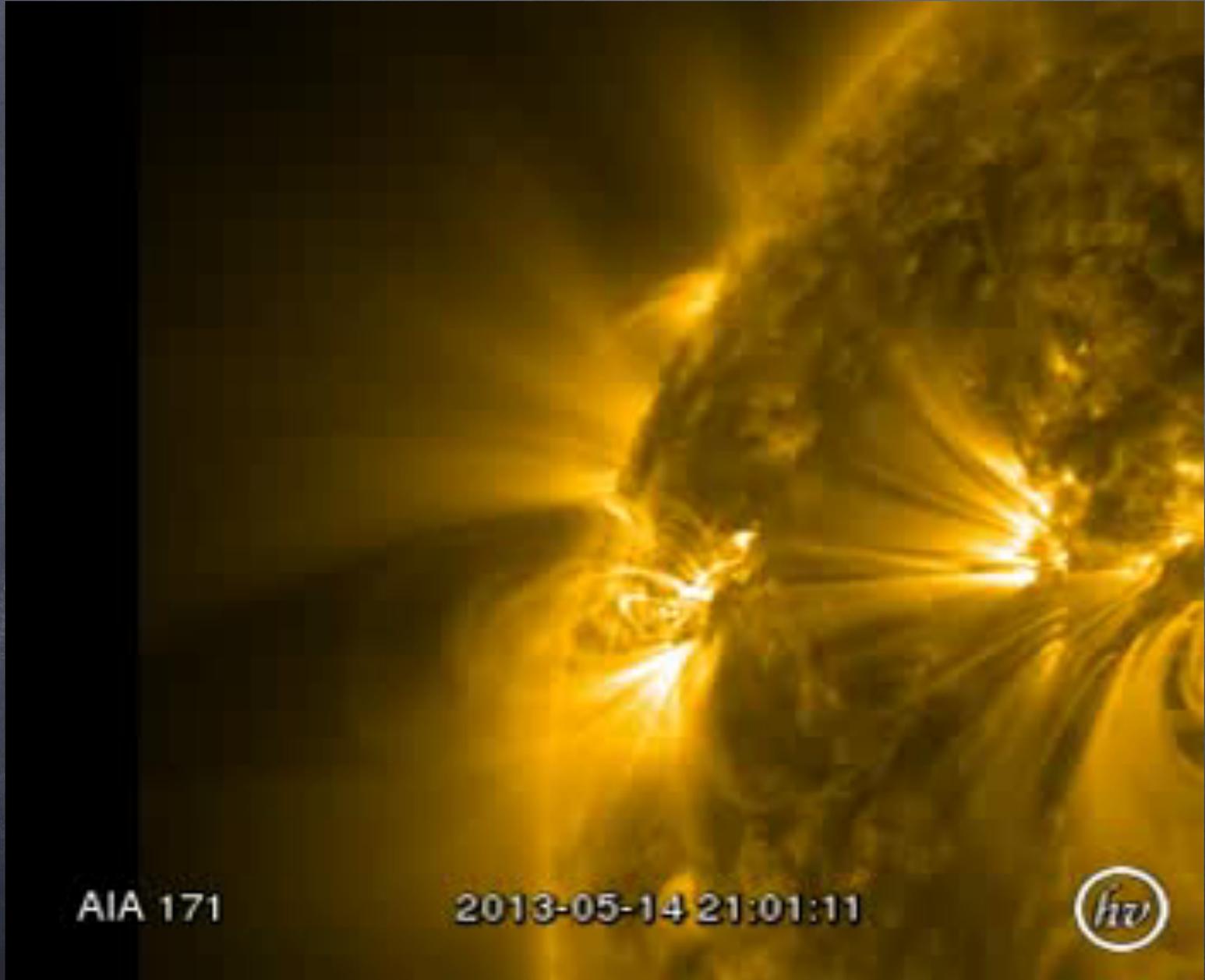


Aug 15

10:10:10 AM EDT

www.helioviewer.org

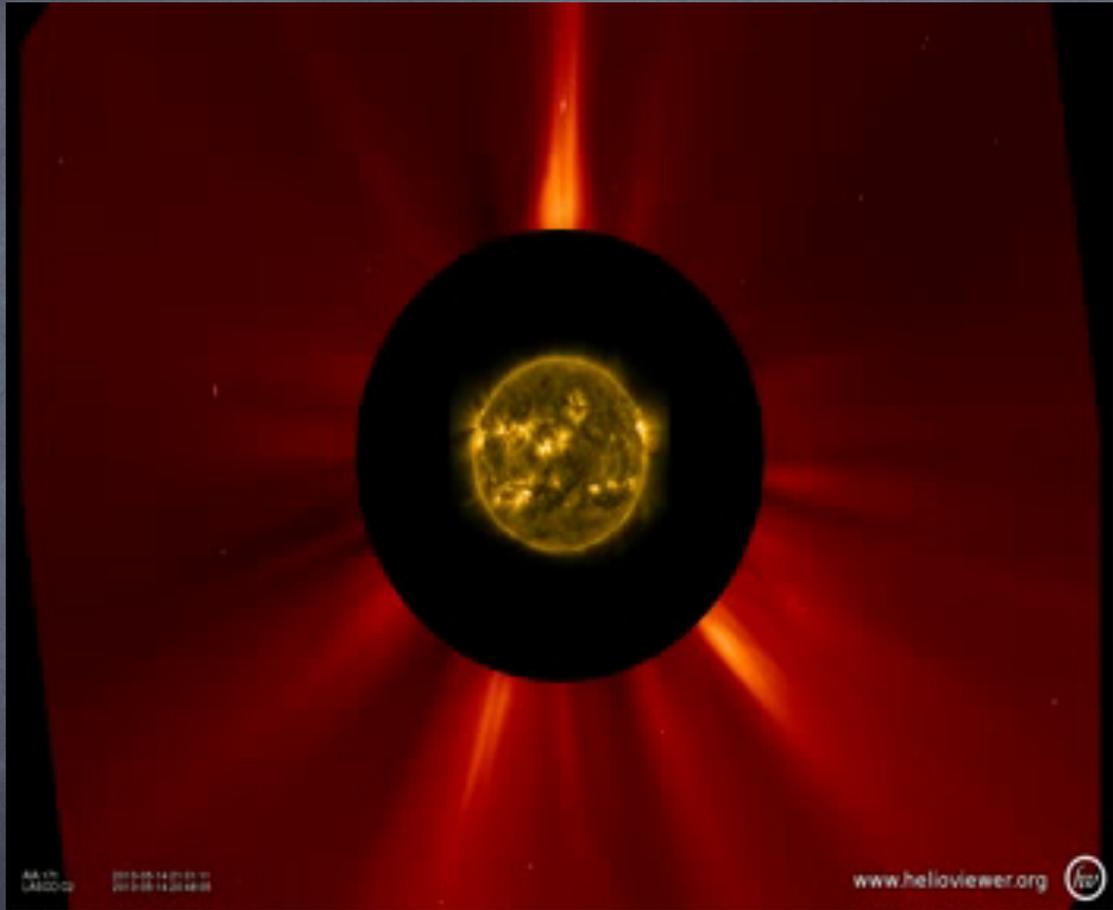




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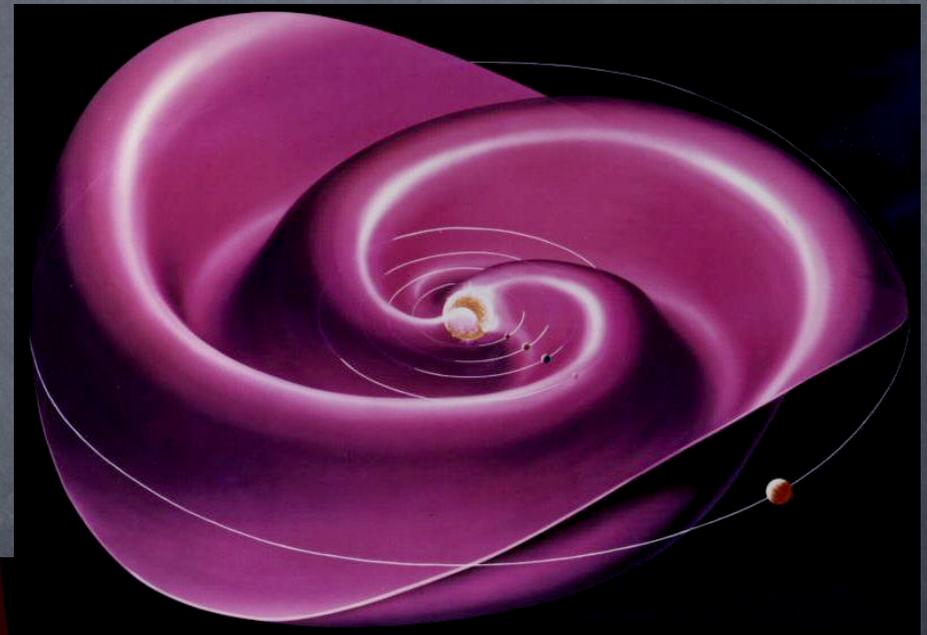
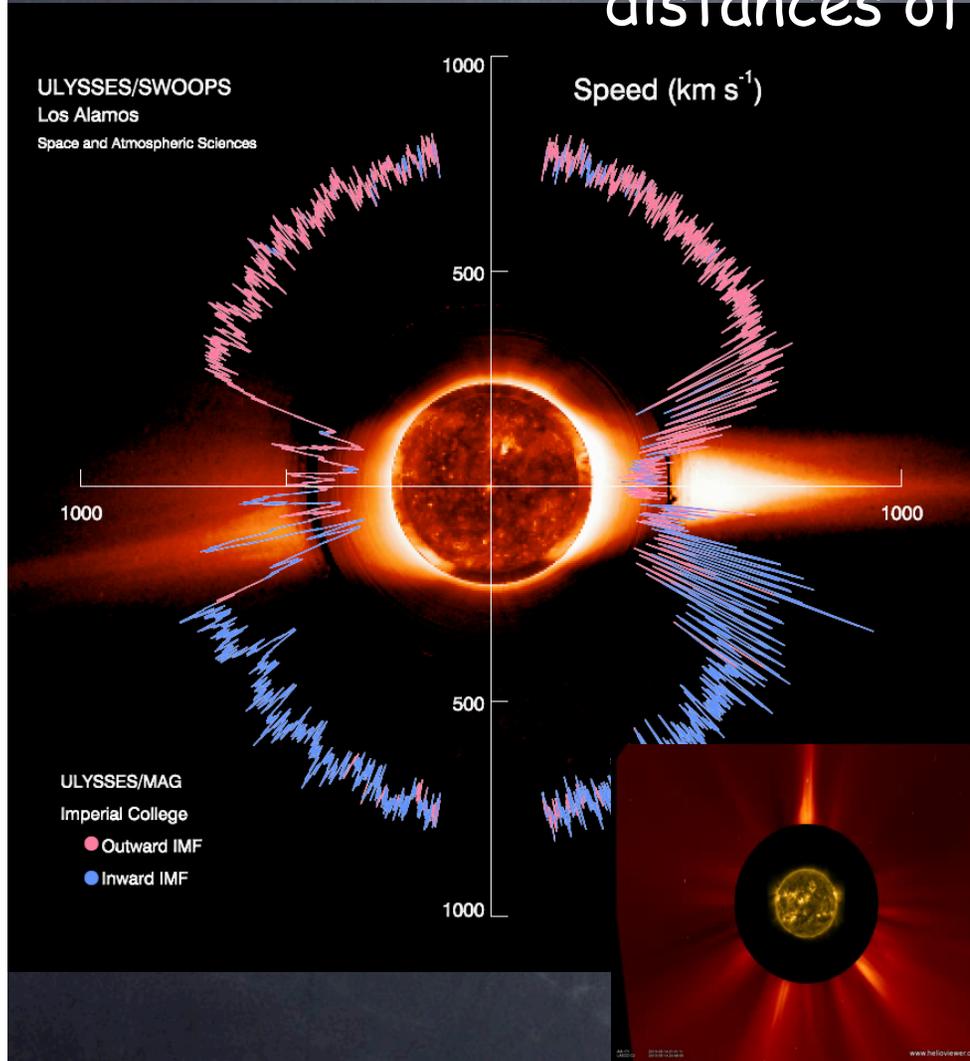
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Solar Wind and IMF

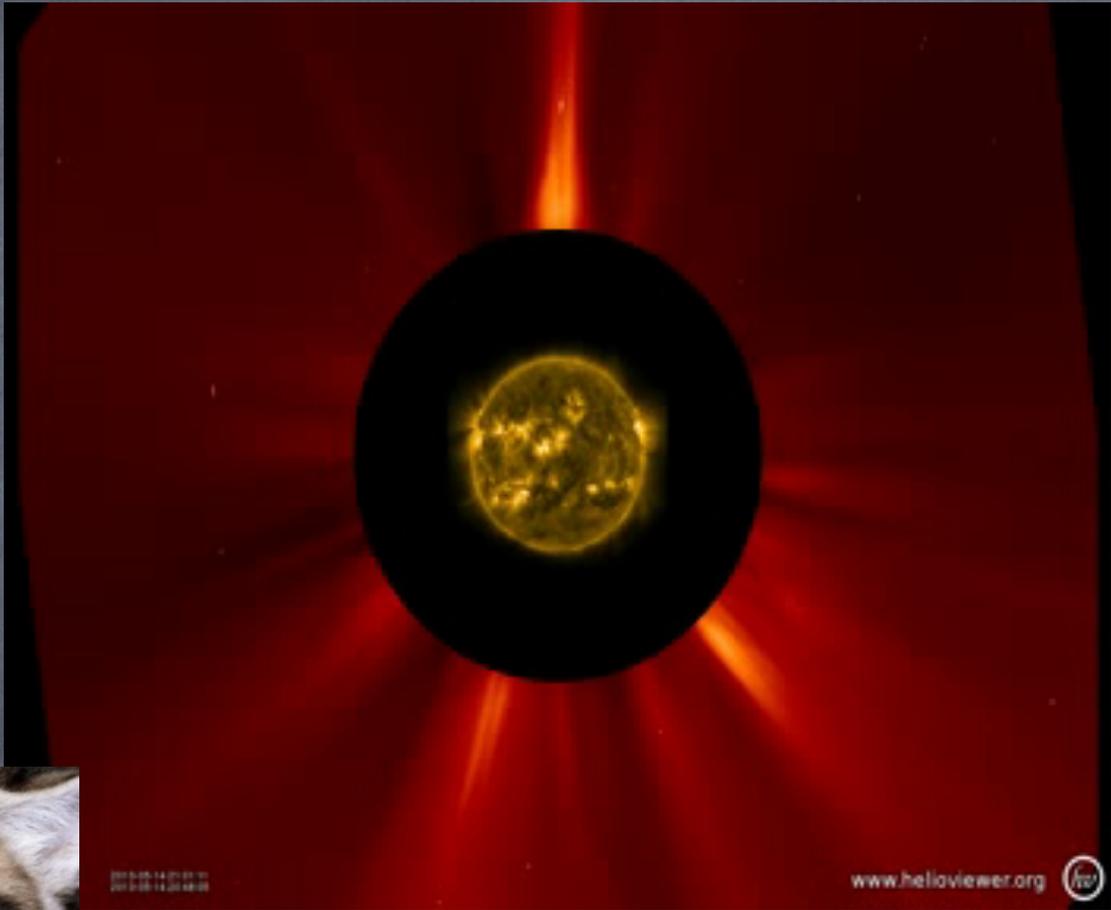
Solar Wind: Charged particles streaming out from Sun
Interplanetary Magnetic Field (IMF): Solar magnetic field at distances of the planets



IMF is twisted into "ballerina skirt" shape by solar rotation.

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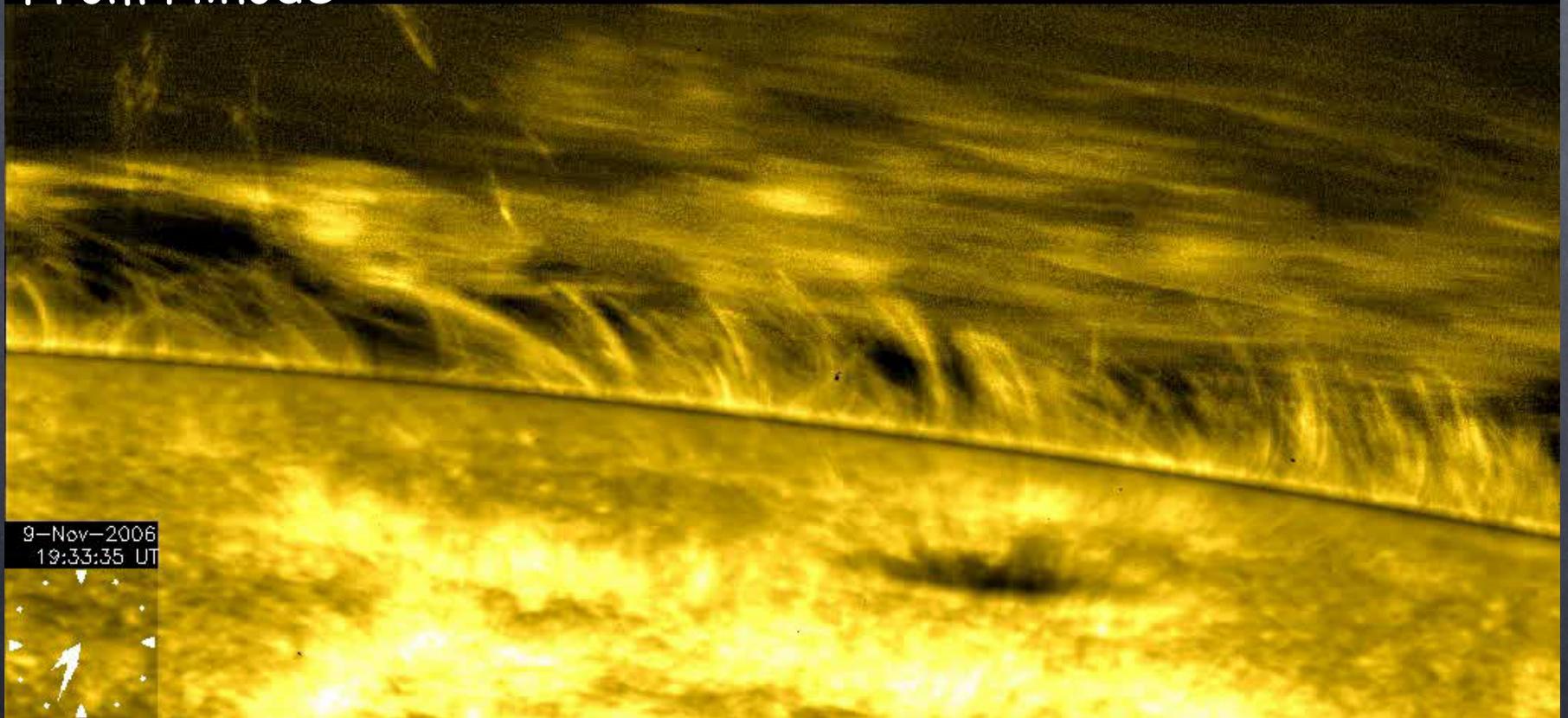
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www.helioviewer.org

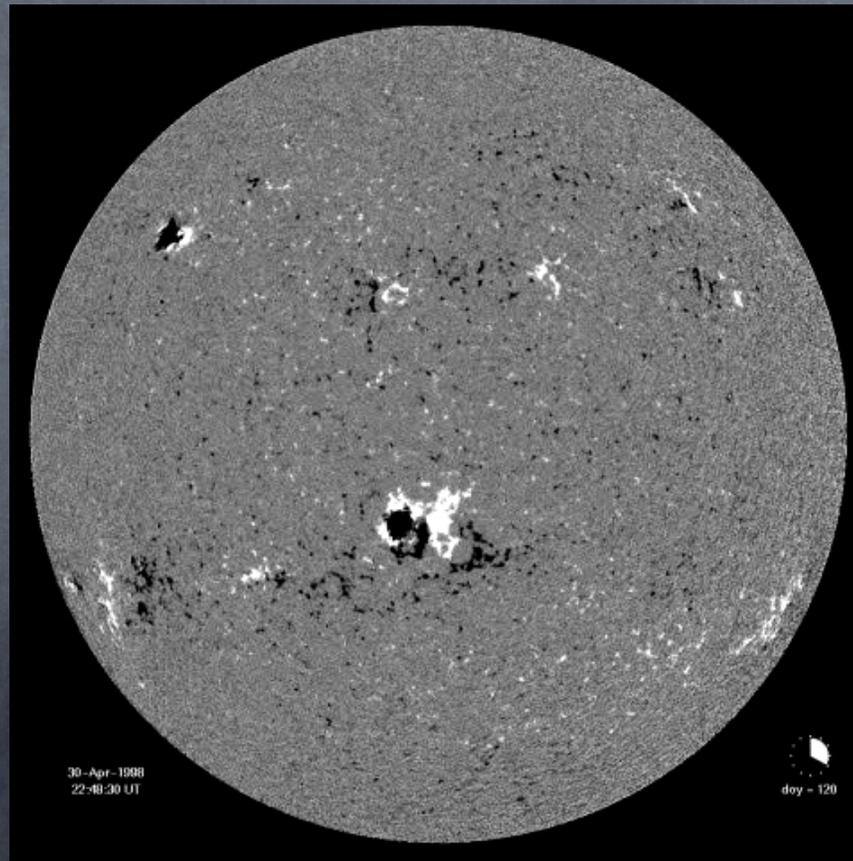


Magnetic field interactions are
very intricate and dynamic

From Hinode



Magnetic field emerges in pairs/
groups of sunspots and also in
diffuse regions

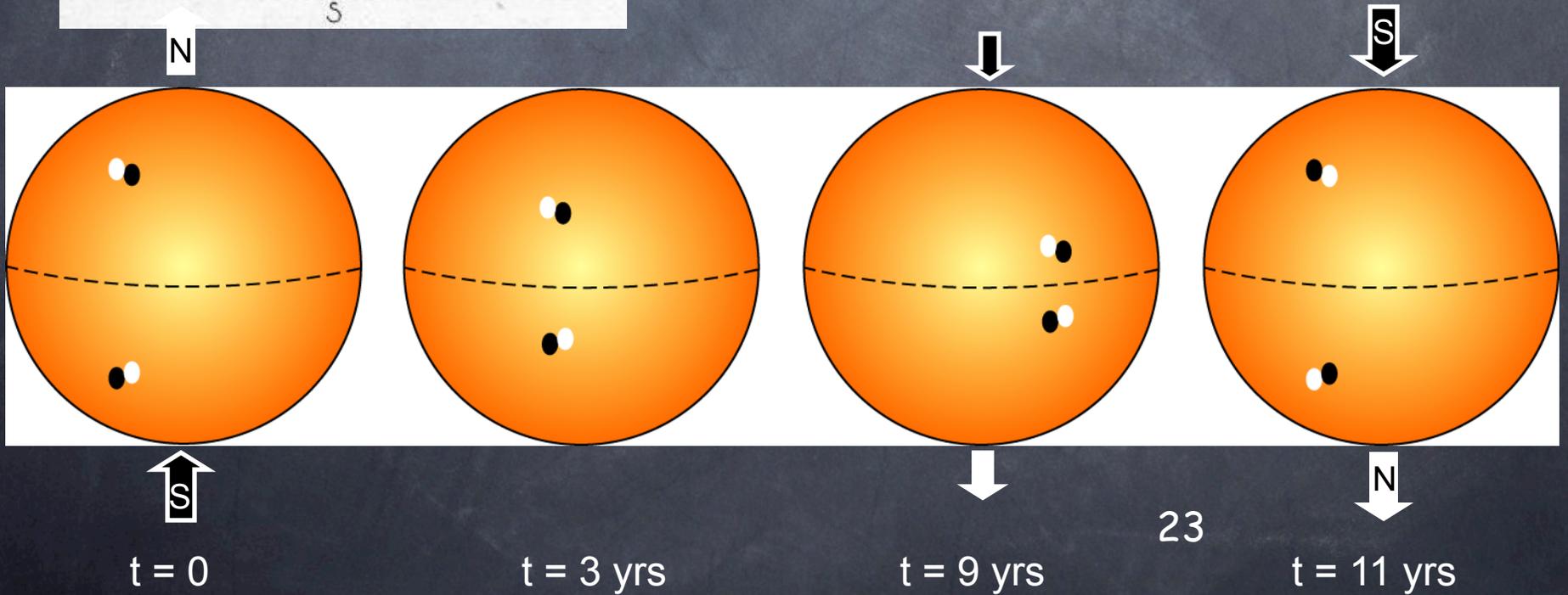
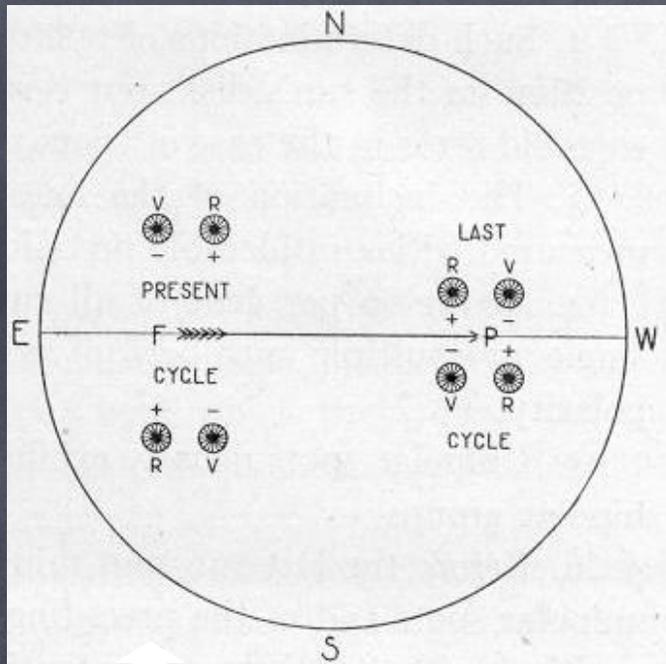


The Sun's Magnetic Cycle

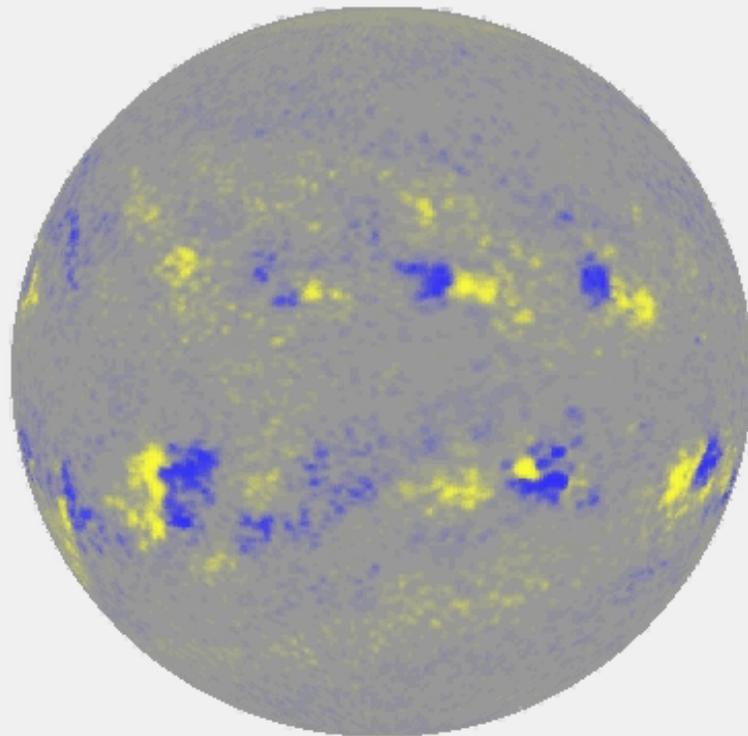
Hale's polarity Law (1919)

Well-organized large scale magnetic field

Changes polarity approximately every 11 years
(22 year magnetic cycle)

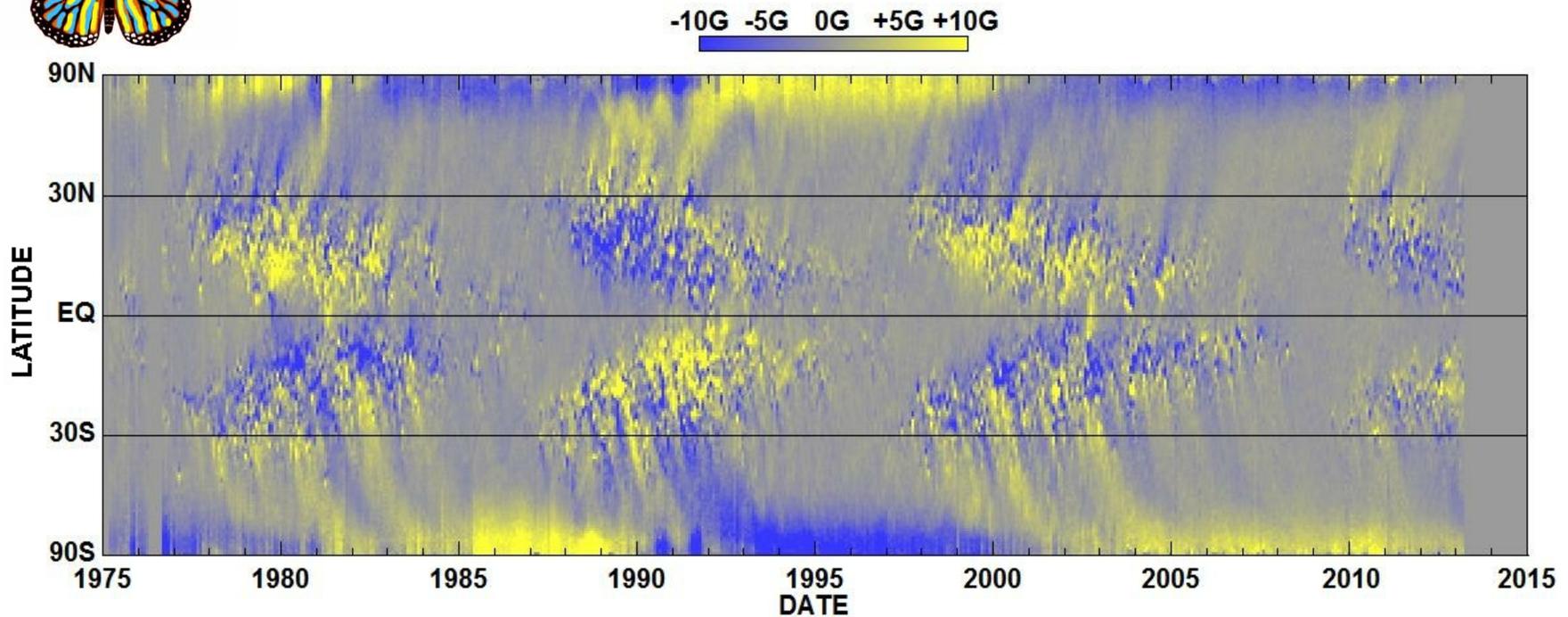


Polarity of leading spots reverses each cycle



Courtesy D. Hathaway

Magnetic Butterfly Diagram



Hathaway/NASA/MSFC 2013/04

Sunspots are a
symptom
of the Sun's
magnetic field.

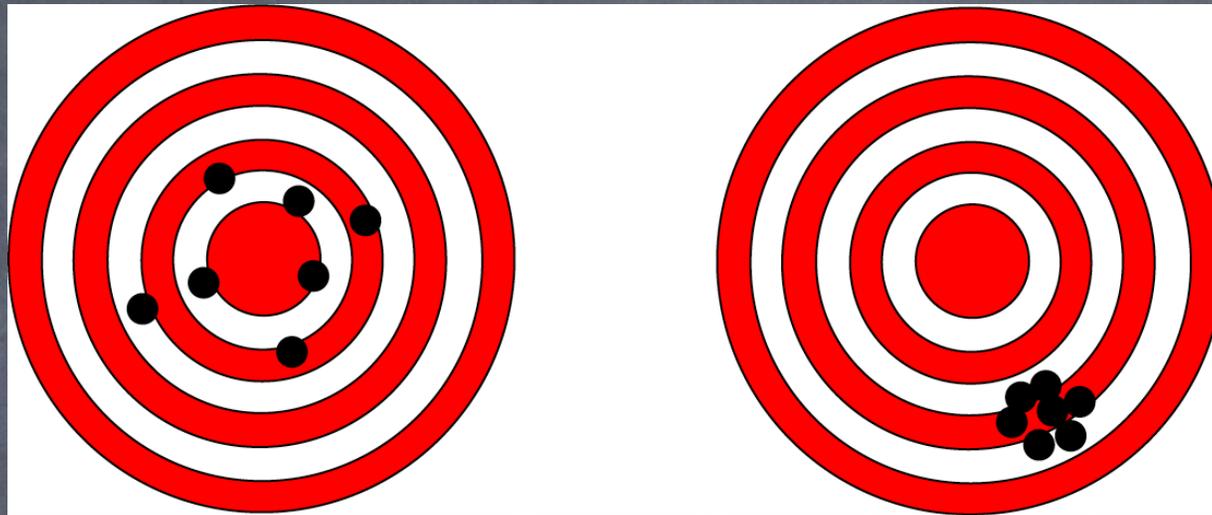
Not the cause.



Is the Sun dimmer now than it
was a few decades ago?



*Just a word on the words
accuracy and precision*

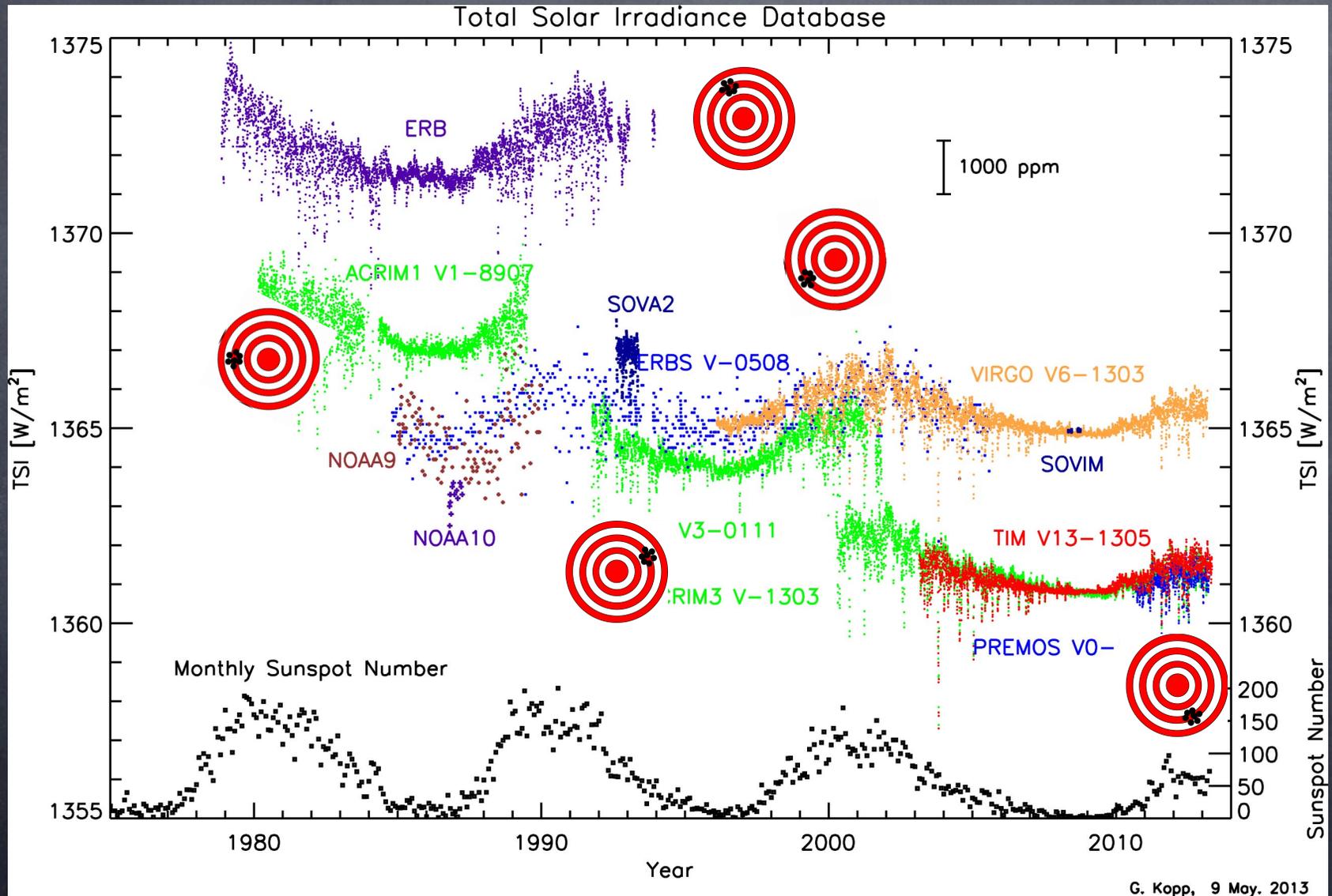


Accurate, but poor precision

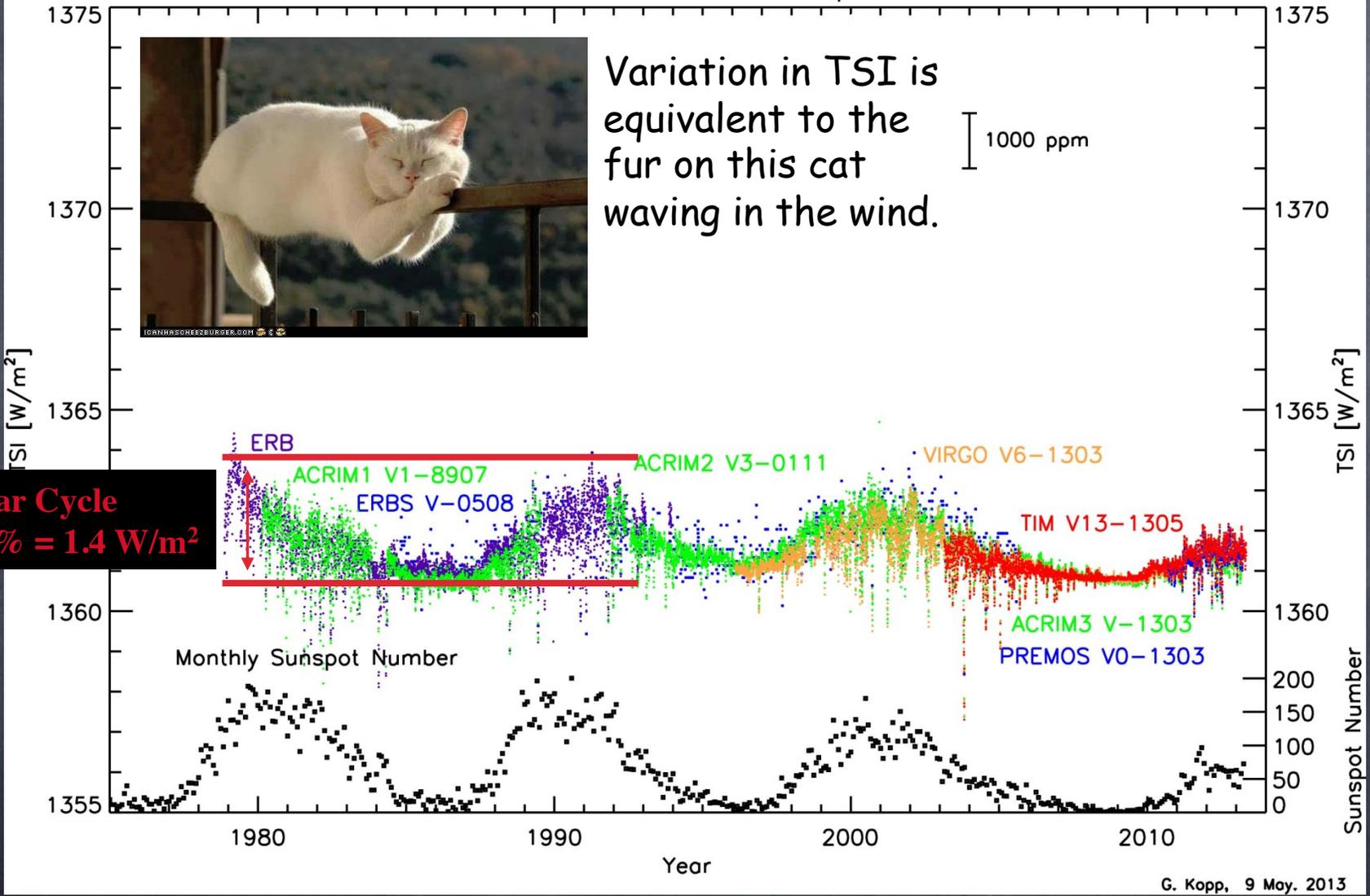
Precise, but poor accuracy

Ideally, scientific measurements are both accurate and precise.

Total Energy in Sunlight

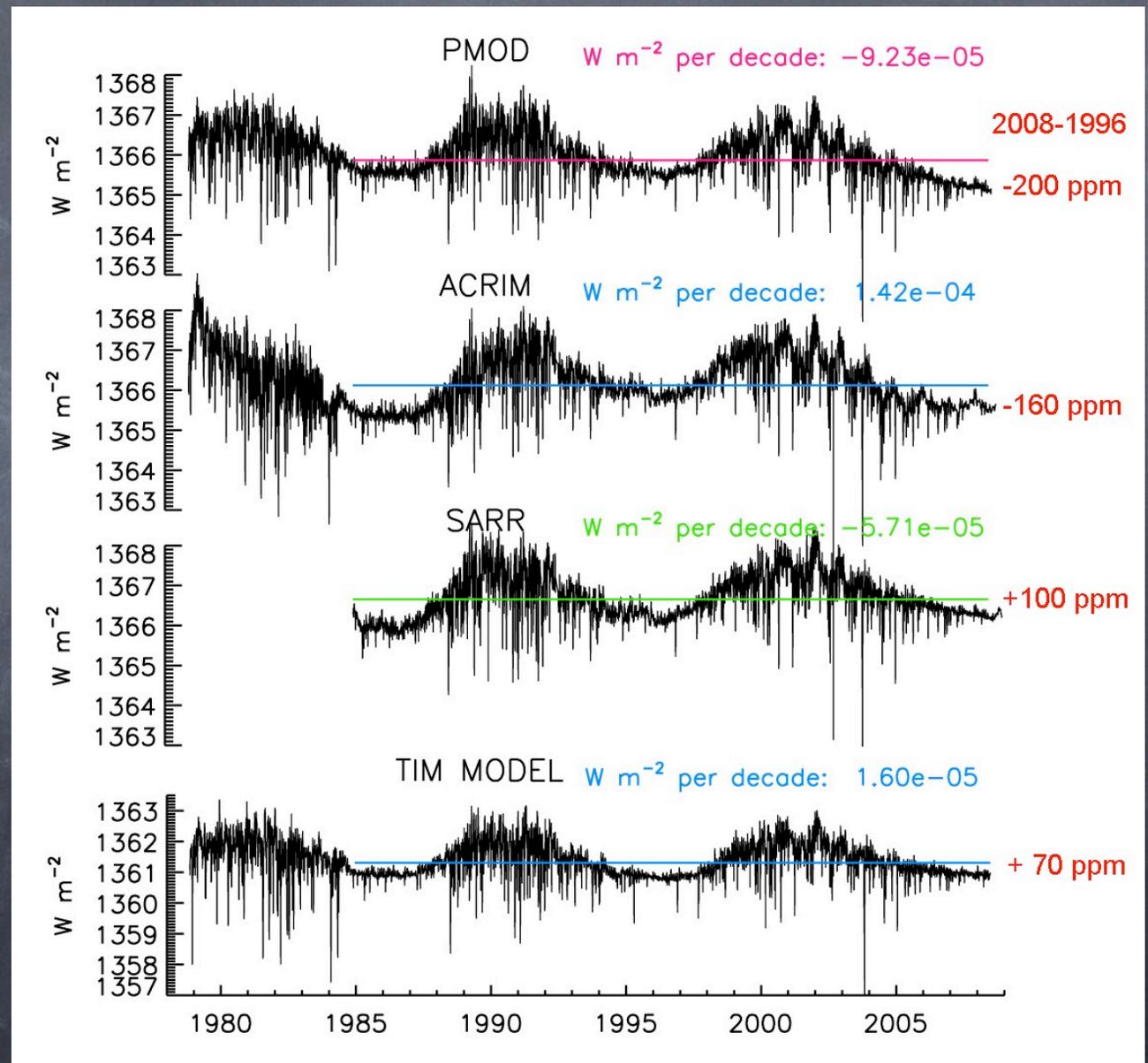


Total Solar Irradiance Composite



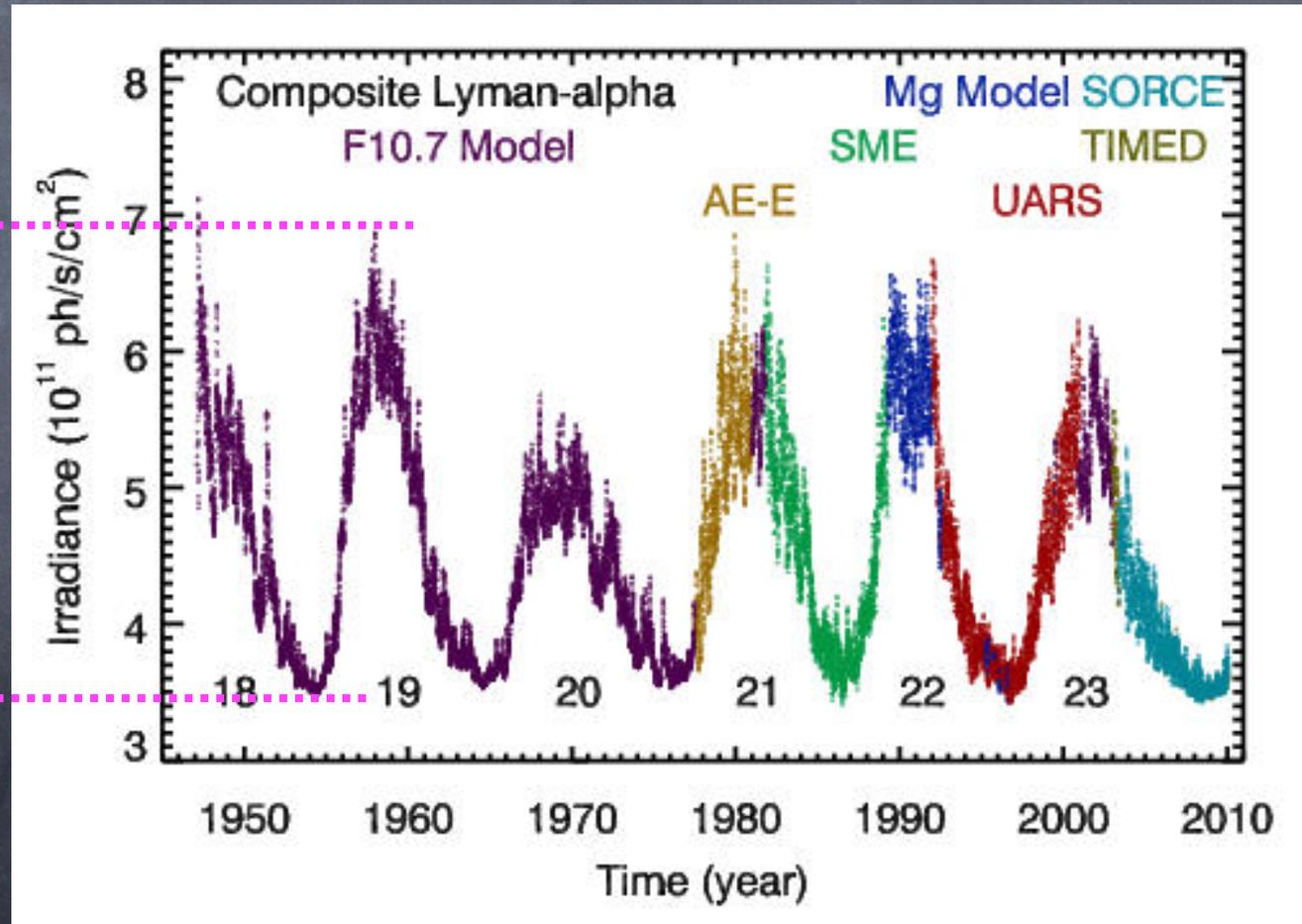
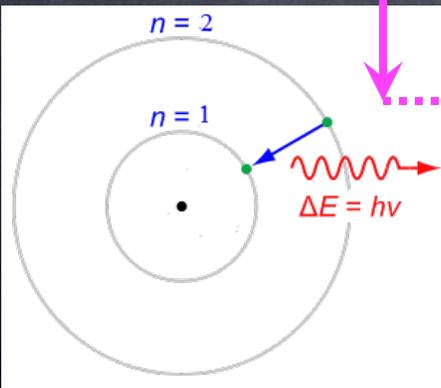
4 TSI Composites: Conflicting Results

- SOHO VIRGO PMOD (Fröhlich) and ACRIM (Willson) composites indicate 2008 TSI is lower than 1996 level
- SOHO VIRGO DIARAD (DeWitte) and SORCE TIM / Model (Lean) composites indicate 2008 TSI is higher
- Uncertainty for 2008-1996 trend is about 100 ppm



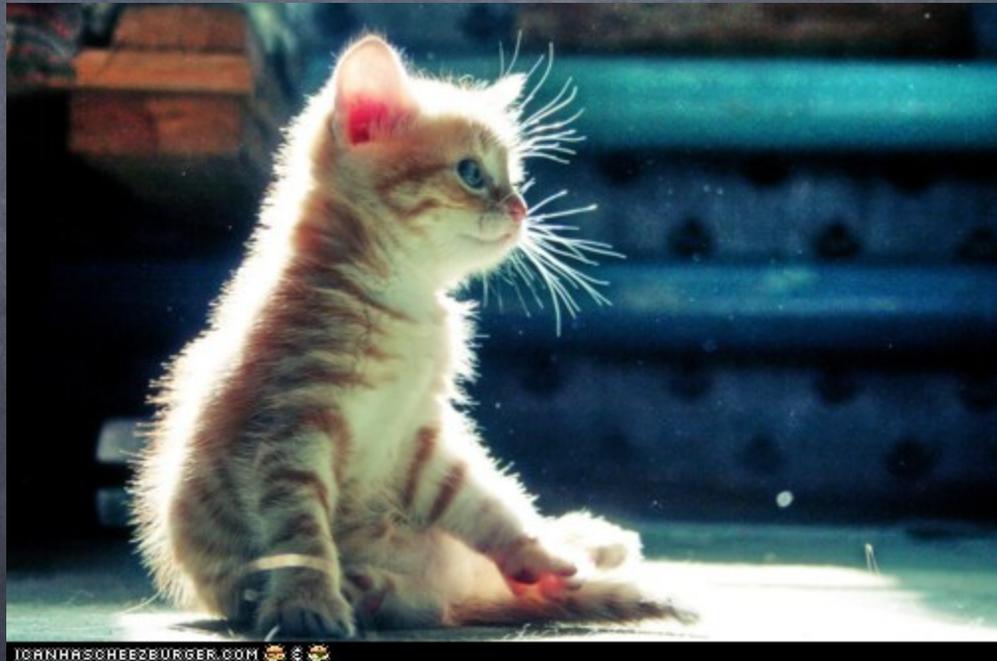
Changes in brightness at a single wavelength

The ultraviolet radiation varies by a factor of ~ 2 over the solar cycle

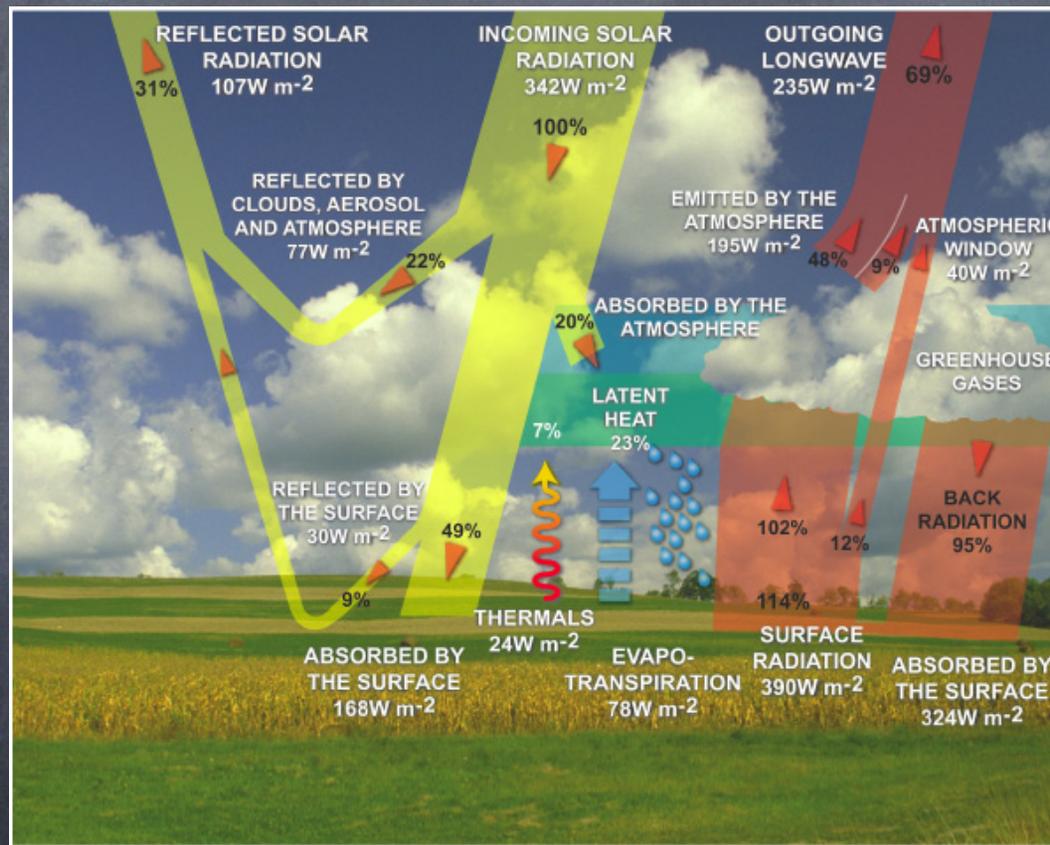
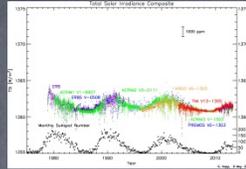


Does this small change in the Sun's brightness matter?

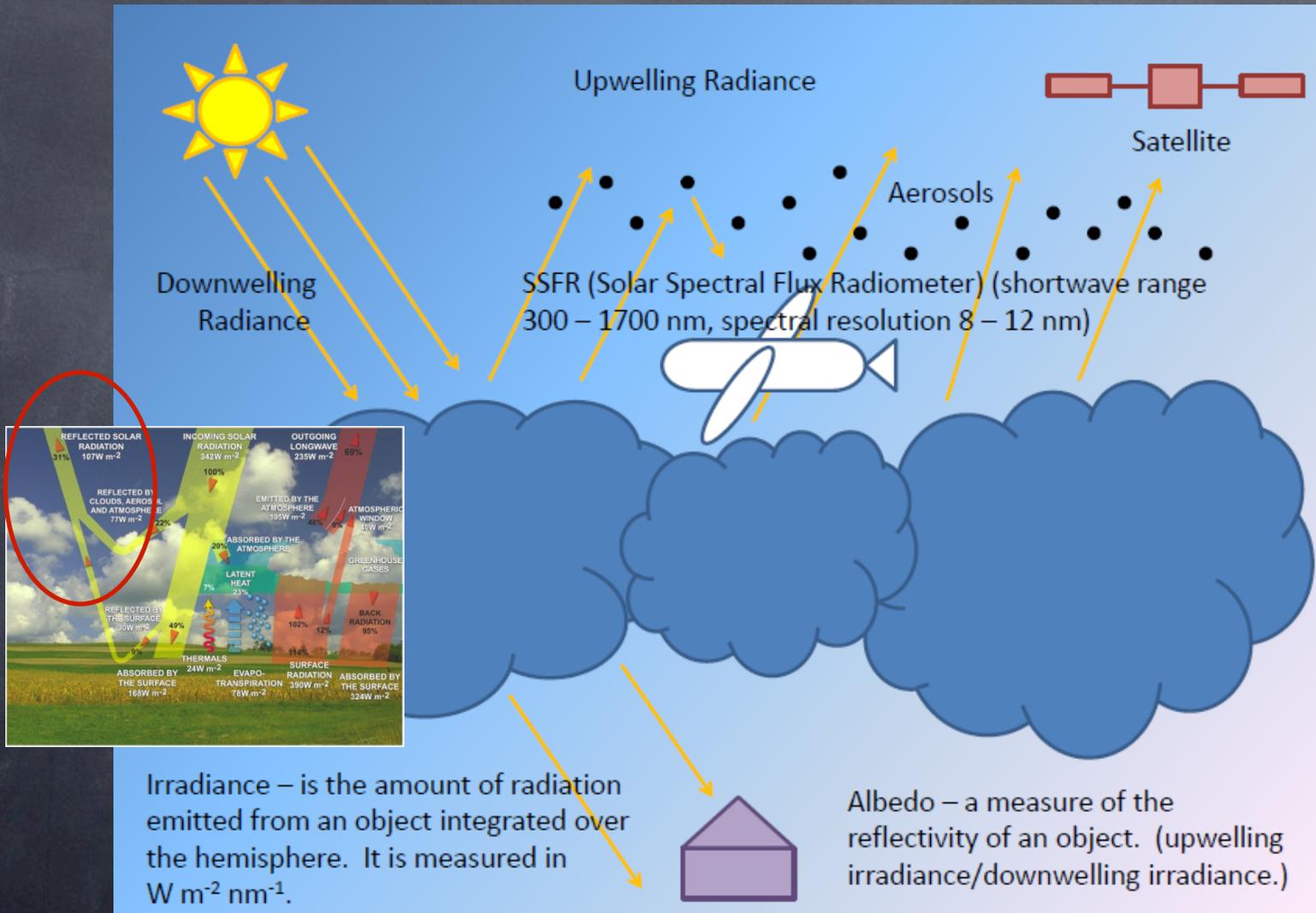
How does solar irradiance influence climate?



Earth's Radiation Budget

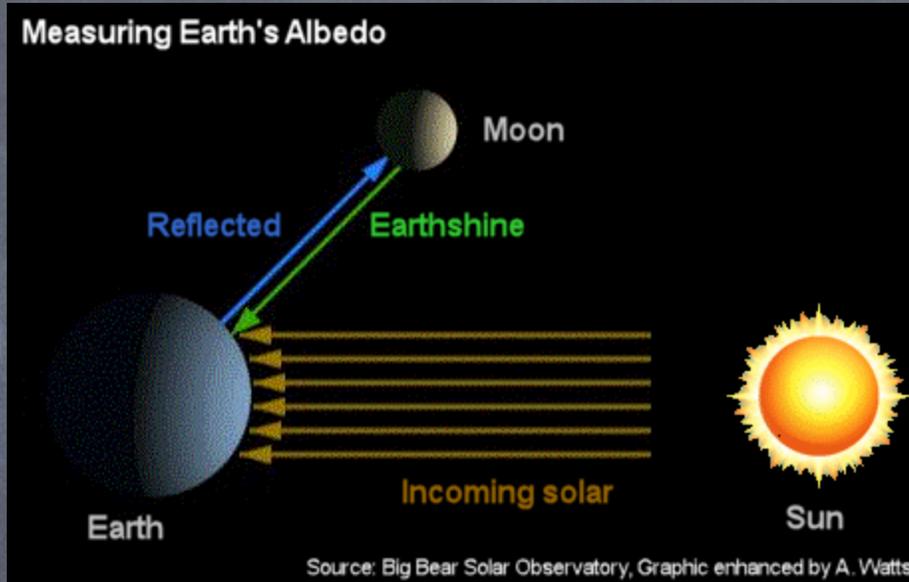


Aircraft & Satellite Measurements

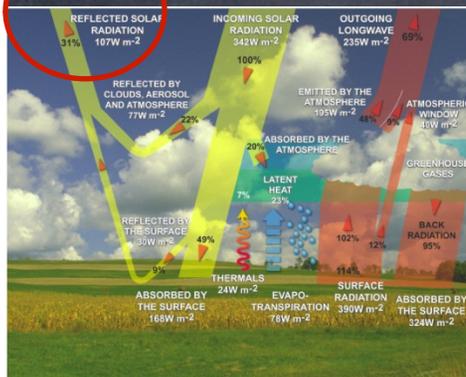


Courtesy Leandra Merola (REU student)

Earthshine

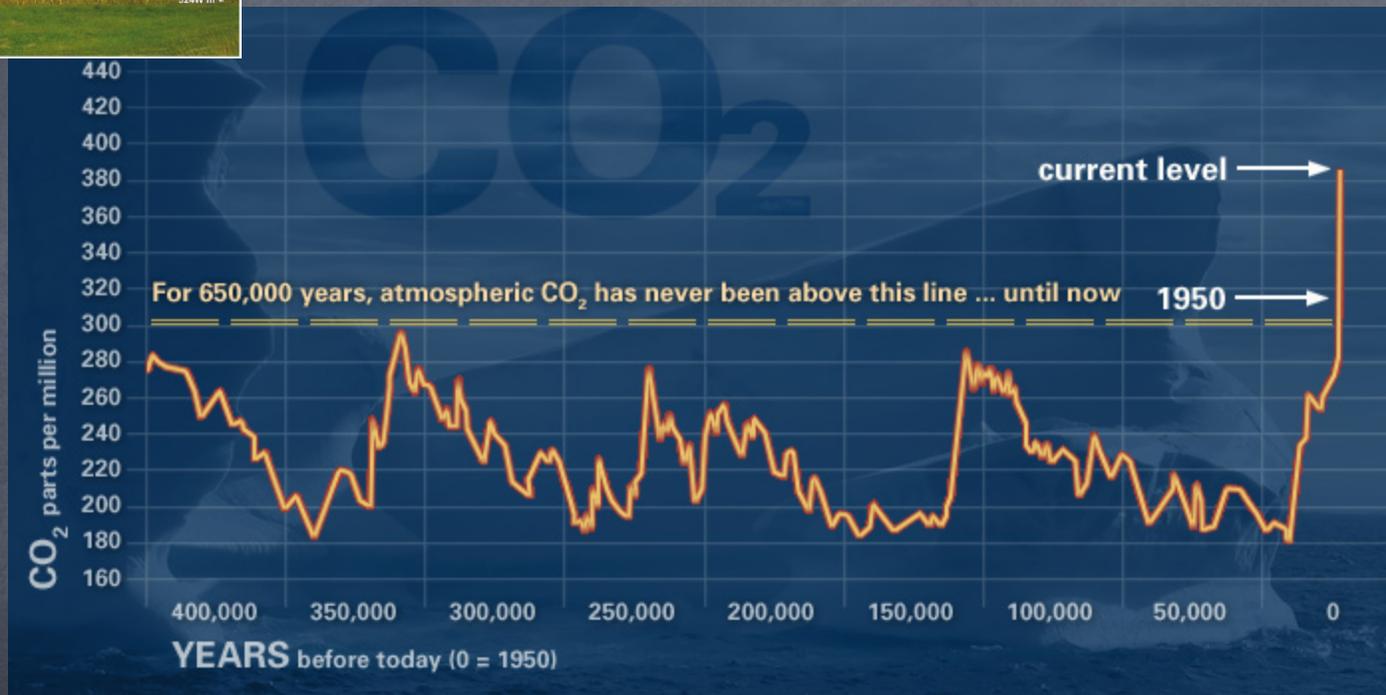
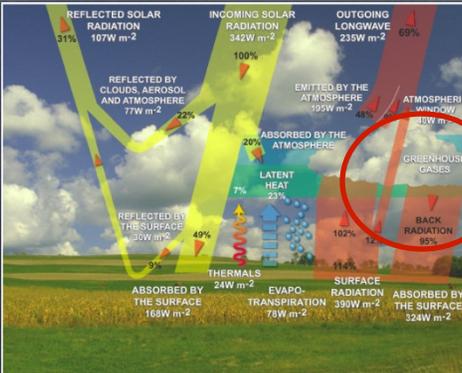


Measures reflection from about 1/3 of the disk, not just a small area.



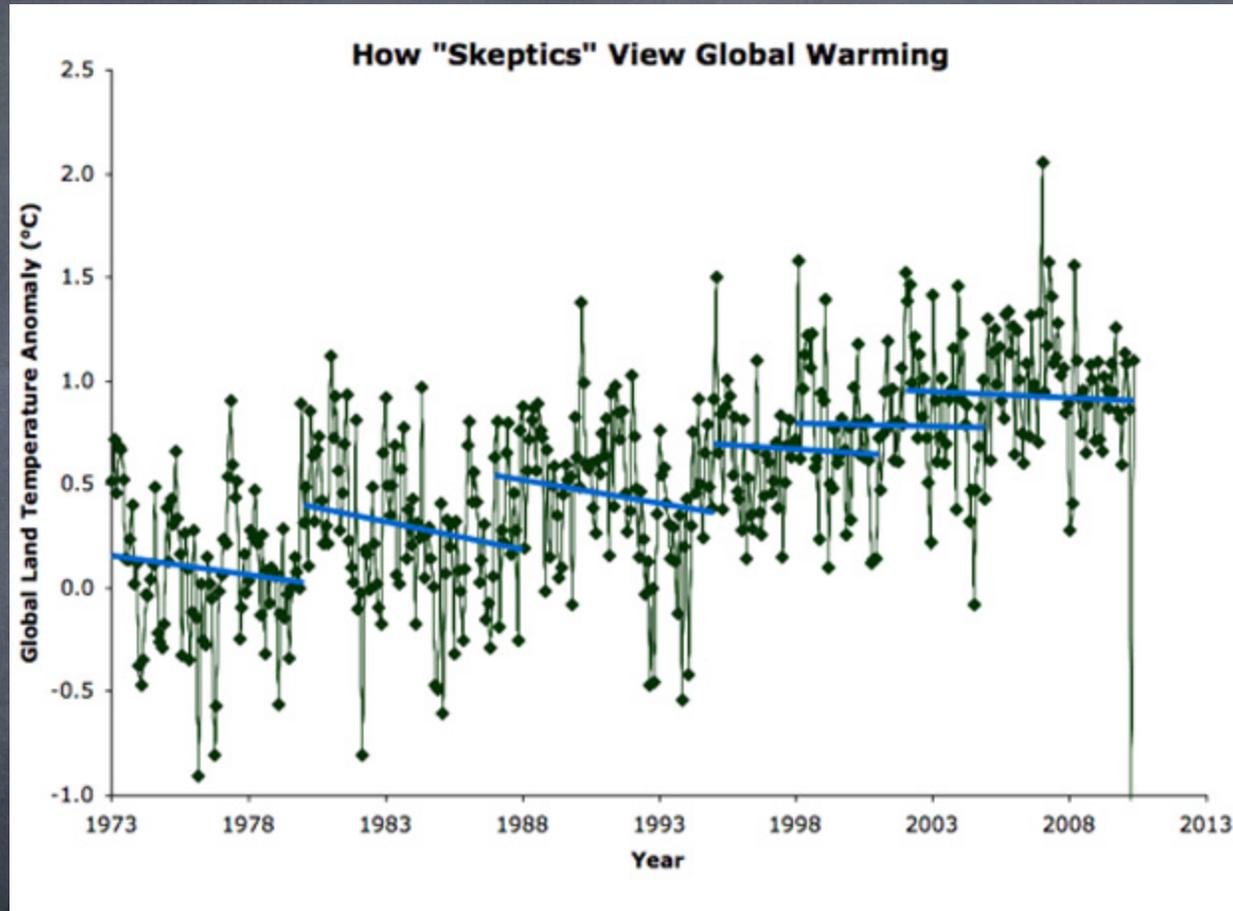
Measurement is not very easy to do, since it requires high accuracy and precision. Signal is fairly low, and atmospheric absorption must be taken into account.

Greenhouse Gases



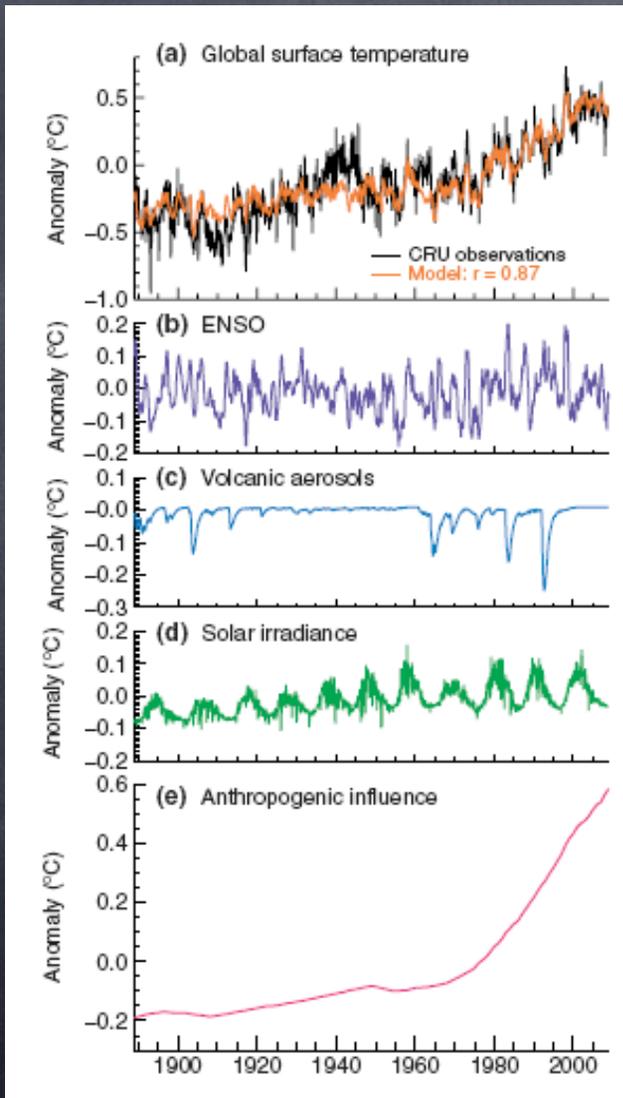
Measured from air bubbles in ice cores.

Temperatures



Contributions to Climate Change

From Lean (2010).

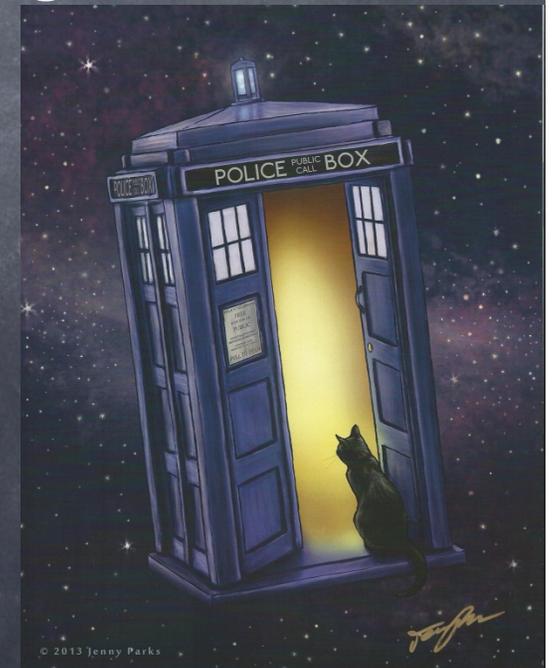


Solar input changes by 0.1% over the solar cycle, and empirically the best fit attributes only about 10% of the warming to the Sun.



Summary

- The Sun is powered by nuclear fusion
- Solar magnetic fields cause it to vary
- Sunlight warms the Earth
- We are still working on understanding all the feedbacks of the climate system

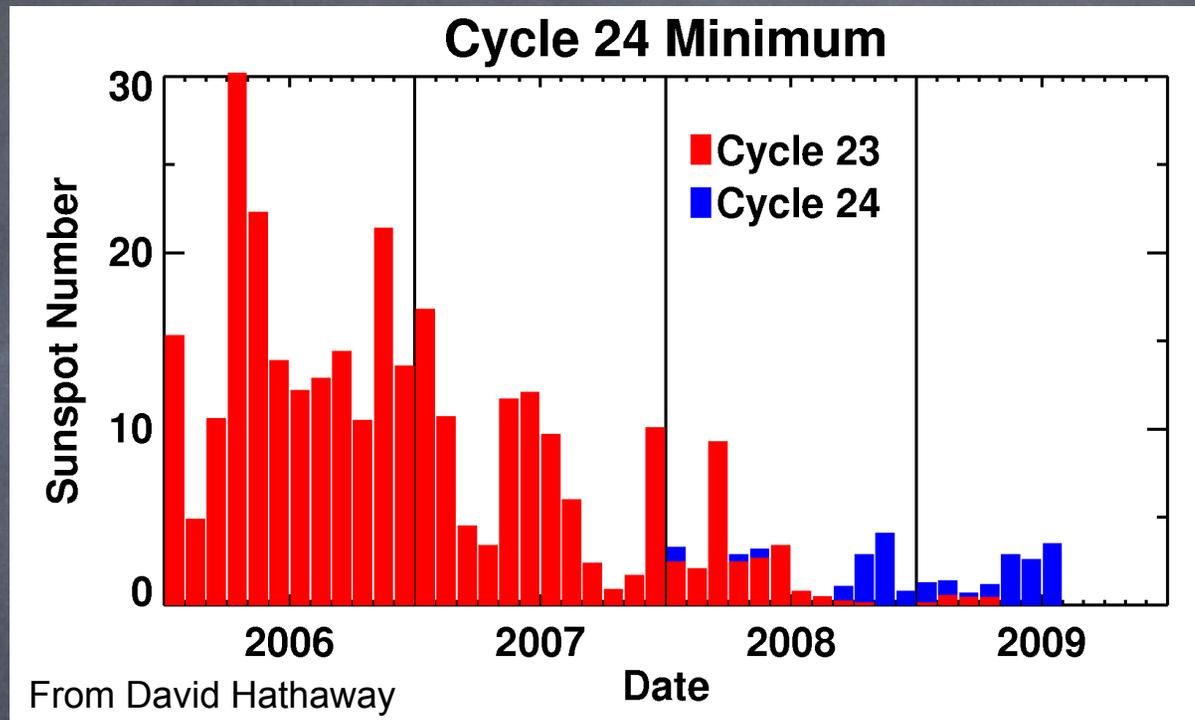


Questions?



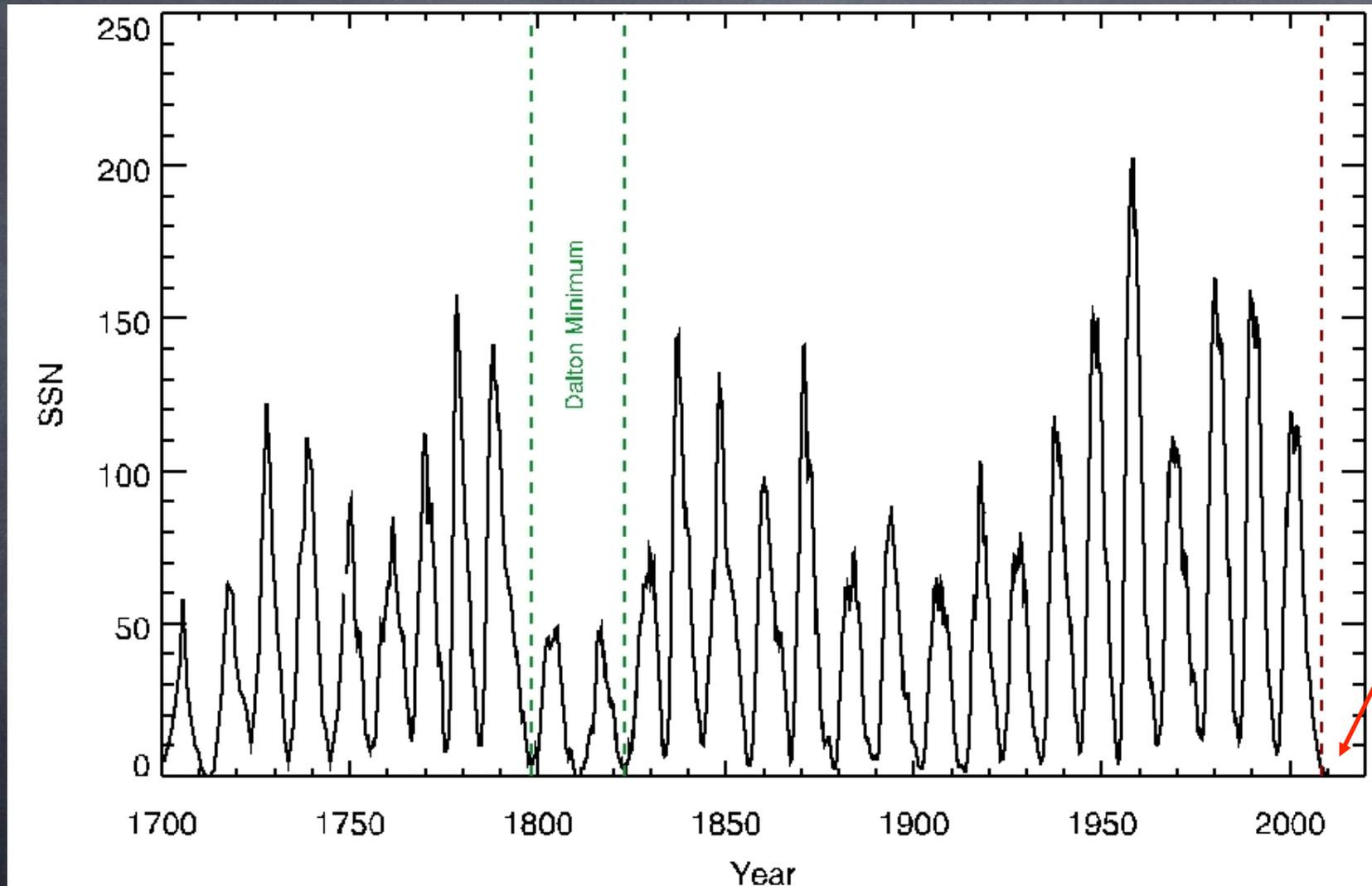
Backup Slides

Overlapping Cycles

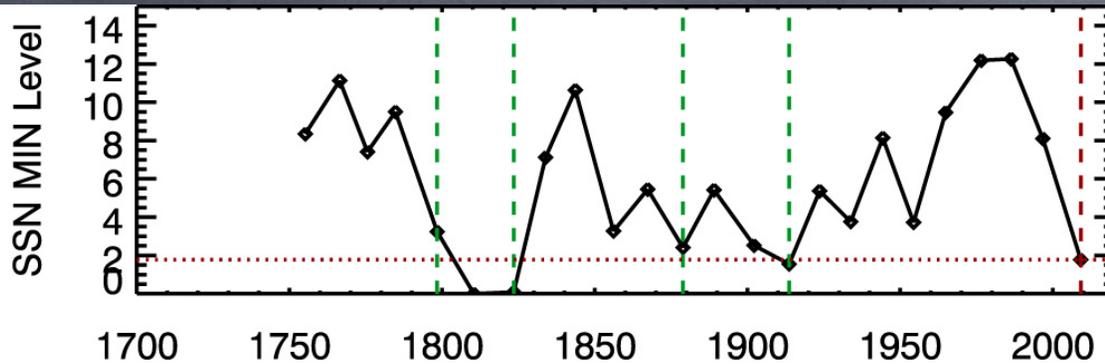


If the new cycle's activity starts appearing before the old cycle's activity fades, do we see the true minimum?

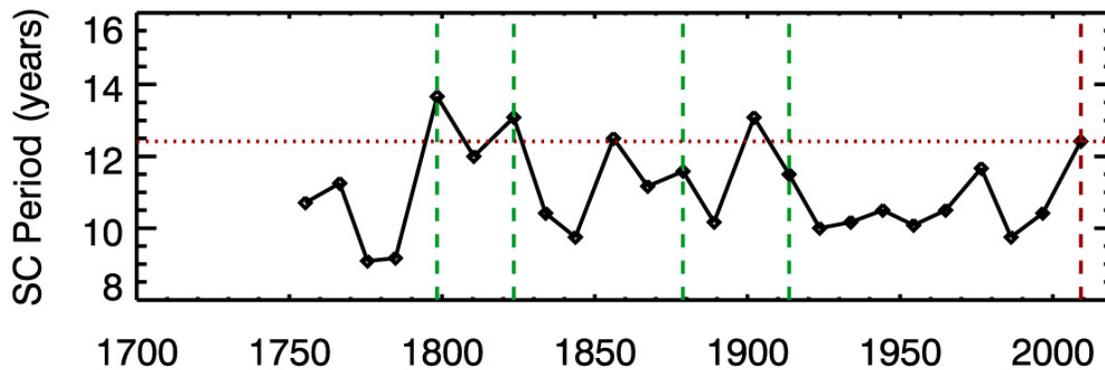
Monthly Averaged Sunspot Numbers



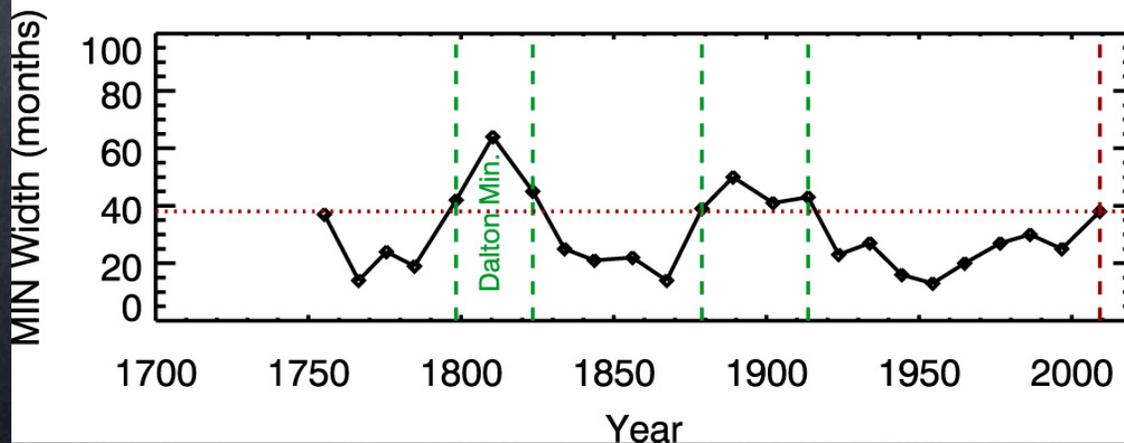
Comparison with earlier cycles



SSN Minimum Level
Lowest since 1920s
(3 of 24 are lower)



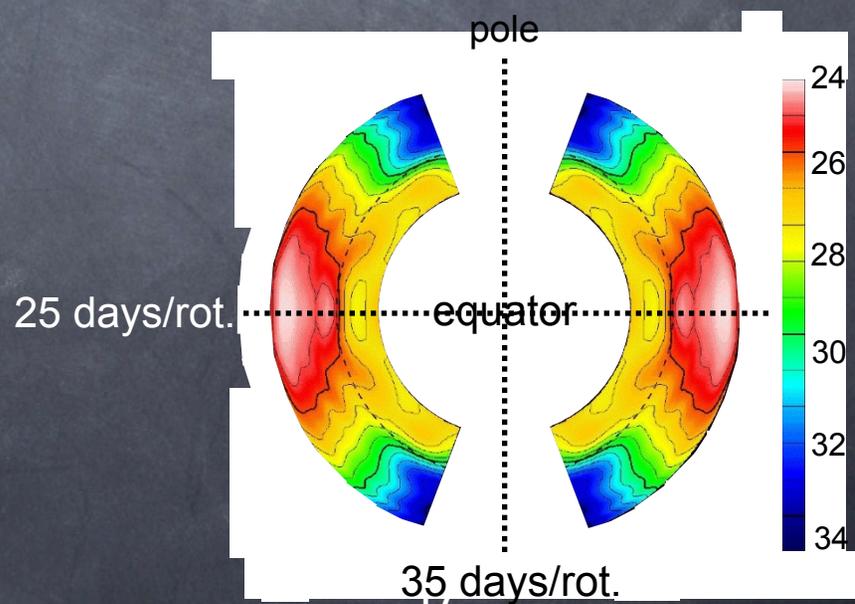
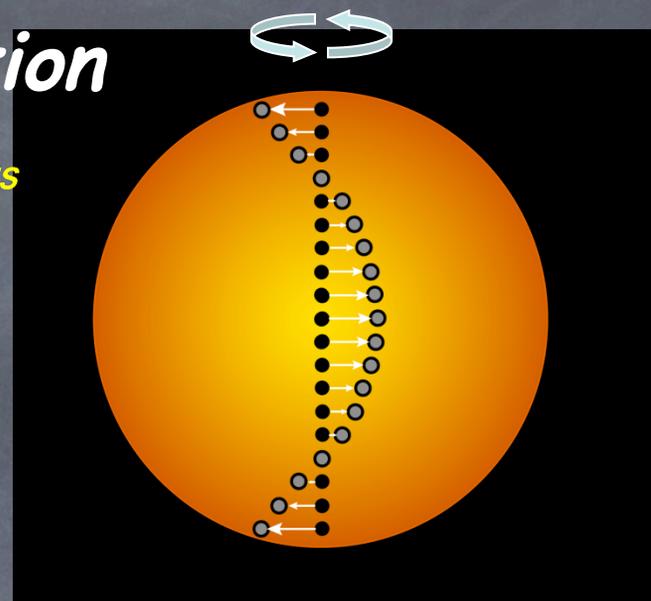
SC Period Length
Longest since 1900
(4 of 24 are longer)



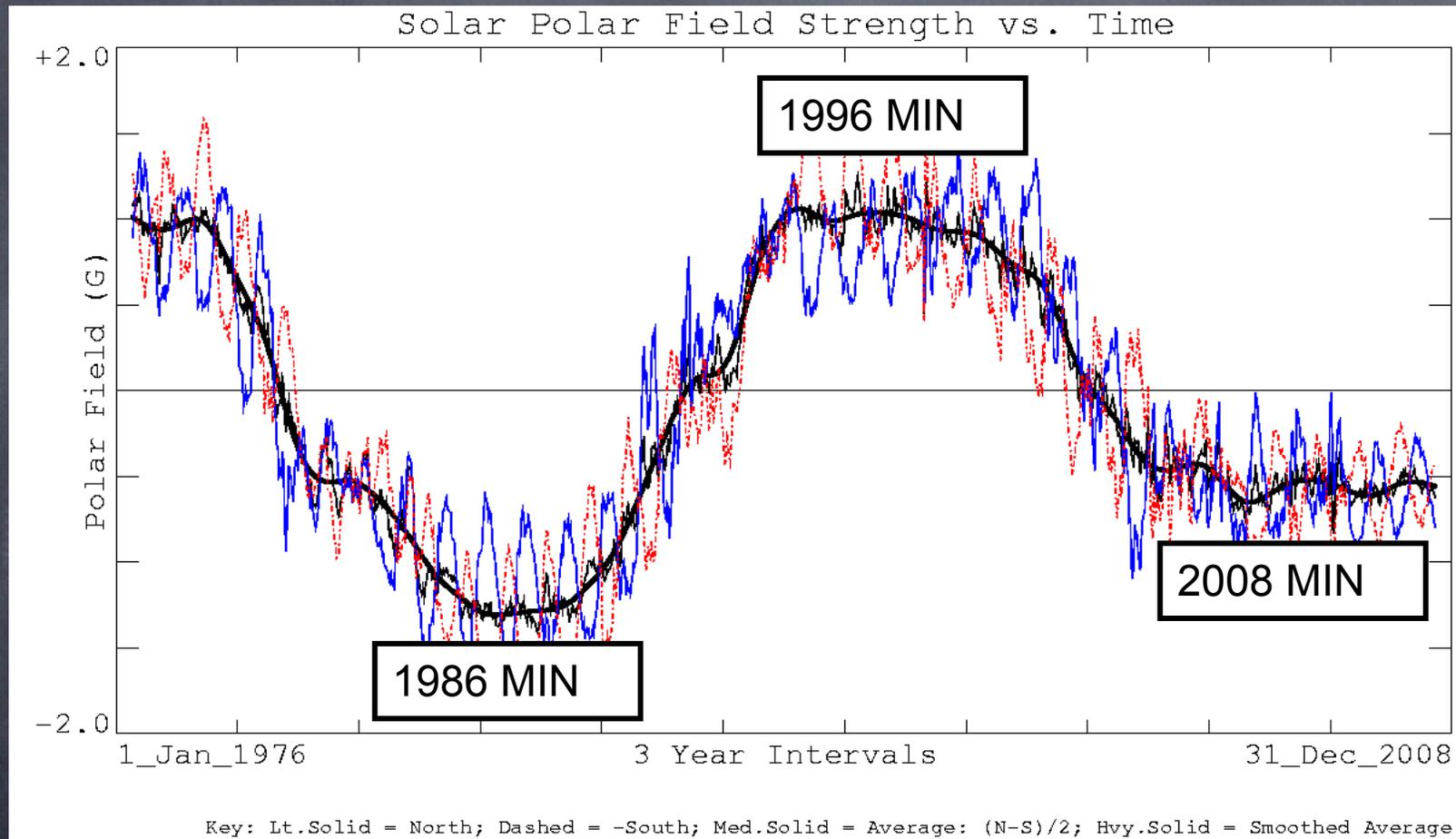
Minimum Duration
Widest since 1920s
(7 of 24 are wider)

The Sun's Differential Rotation

1858: Carrington and Sporer independently observed sunspots located at higher latitudes are carried around the Sun slower than sunspots at lower latitudes

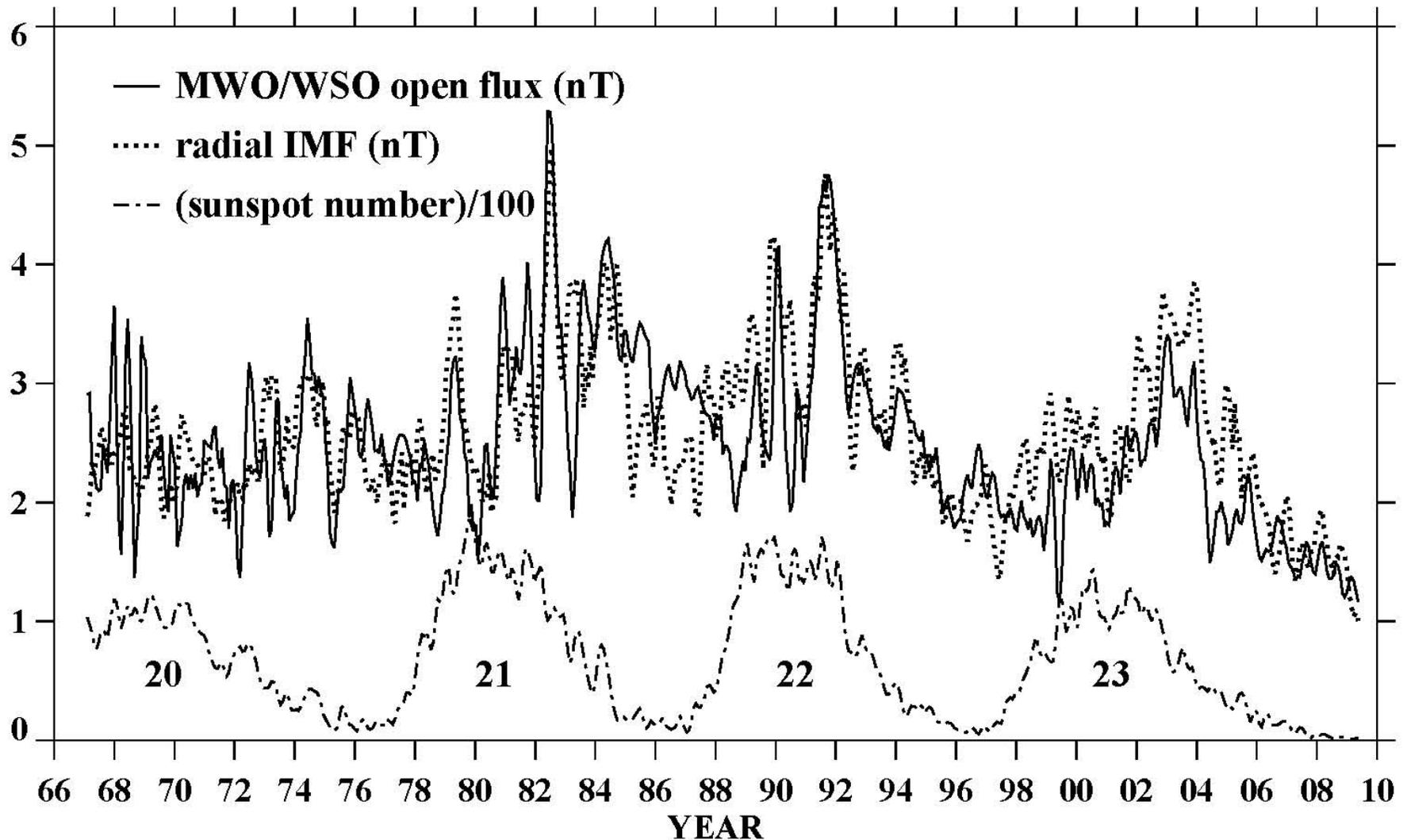


Field



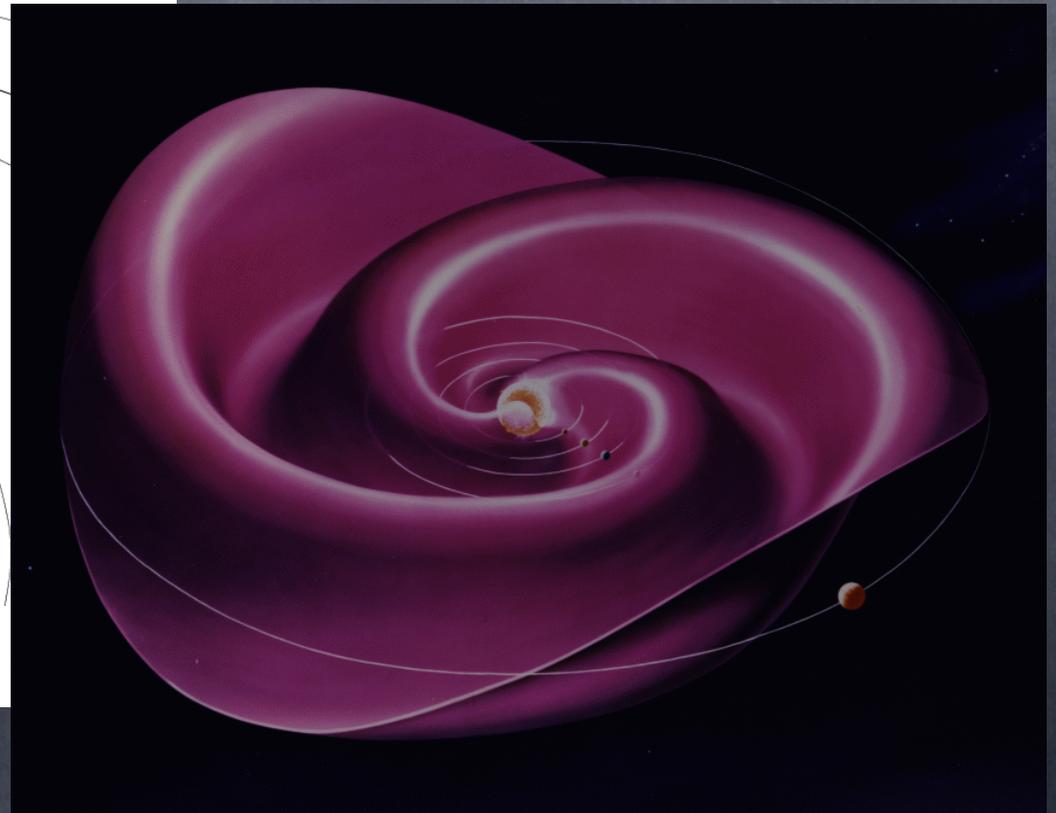
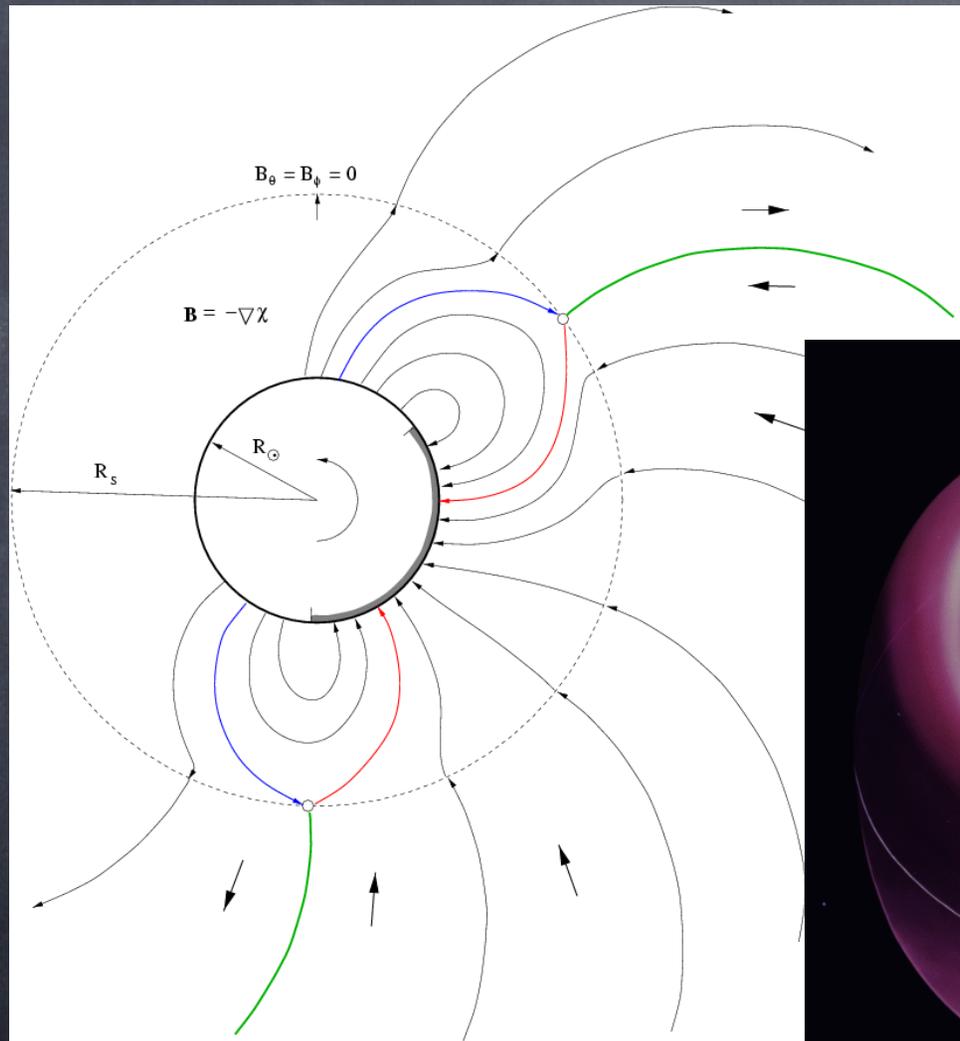
40% weaker than in previous minima.

"Open" Magnetic Field



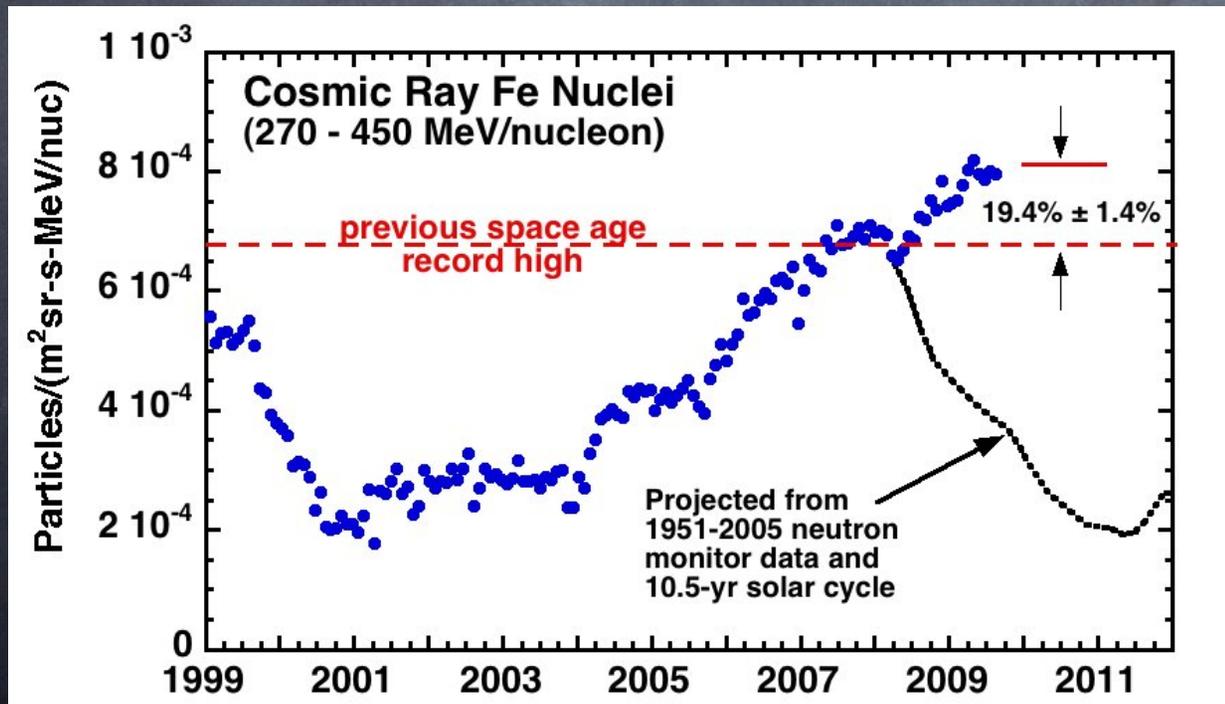
45% Less Open Flux than Any Cycle in the Past 49 Years

What does "open" mean?



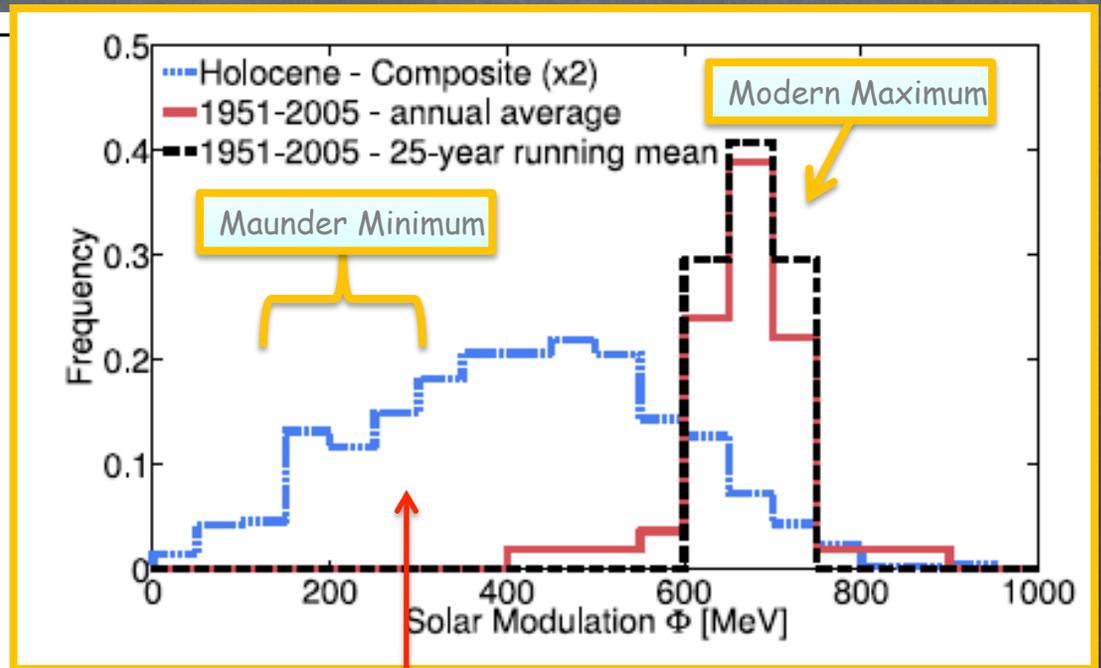
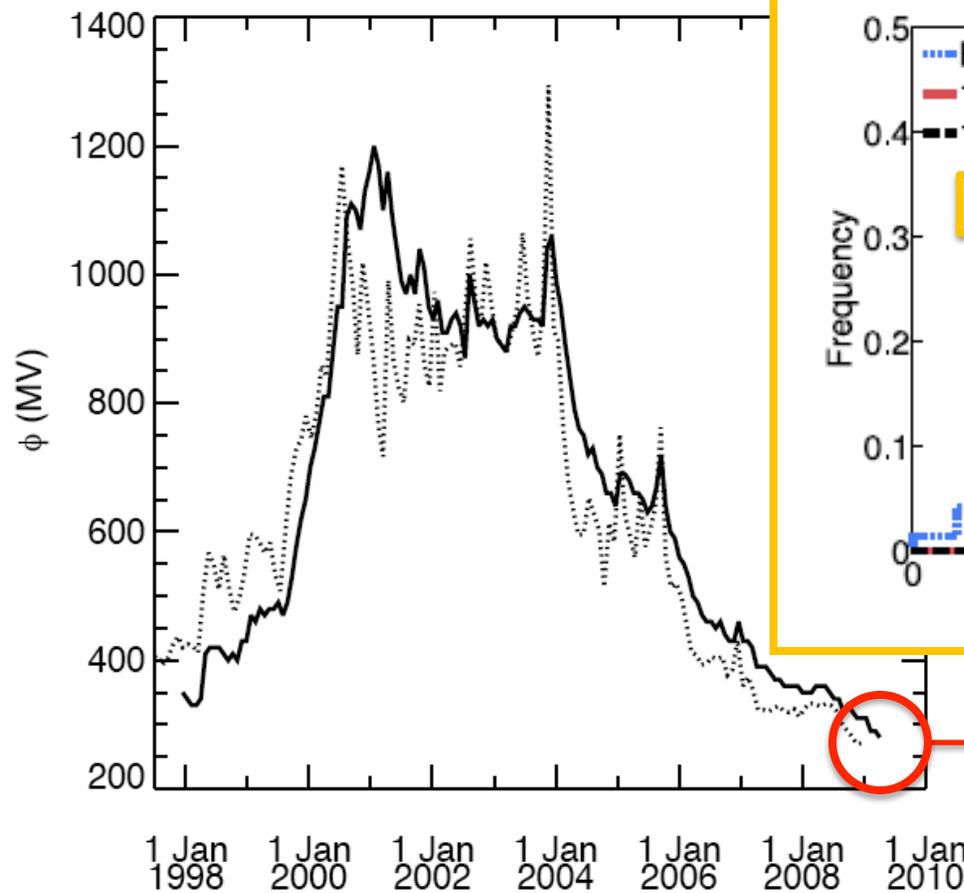
Record Low Interplanetary Magnetic Field

Record HIGH
Galactic Cosmic Rays



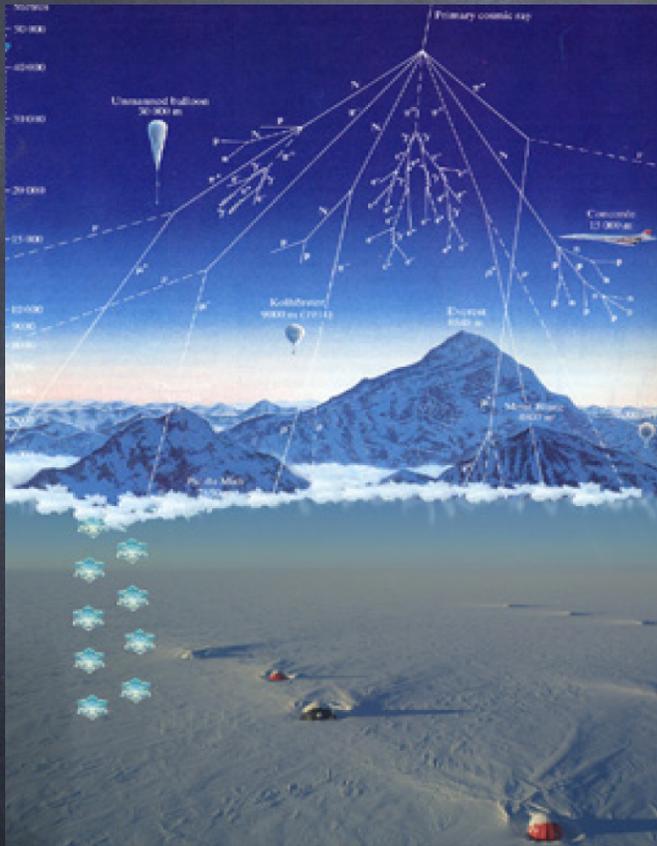
- Highest level of cosmic rays in the 54 year record.

Comparison to estimates for Maunder minimum



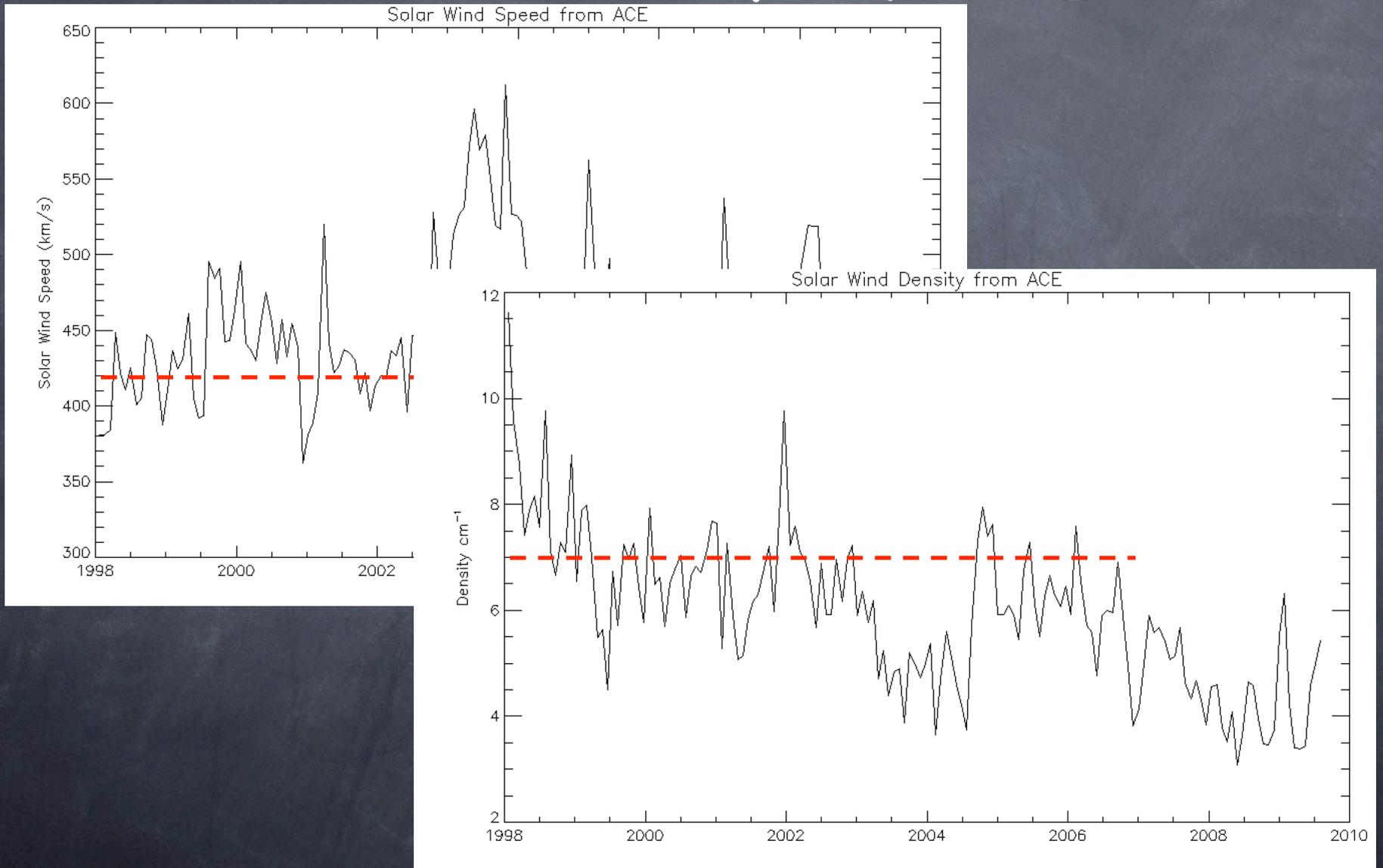
Very low compared to last 5 cycles.
Approaching extreme minimum state.

Do we care about Cosmic Rays?

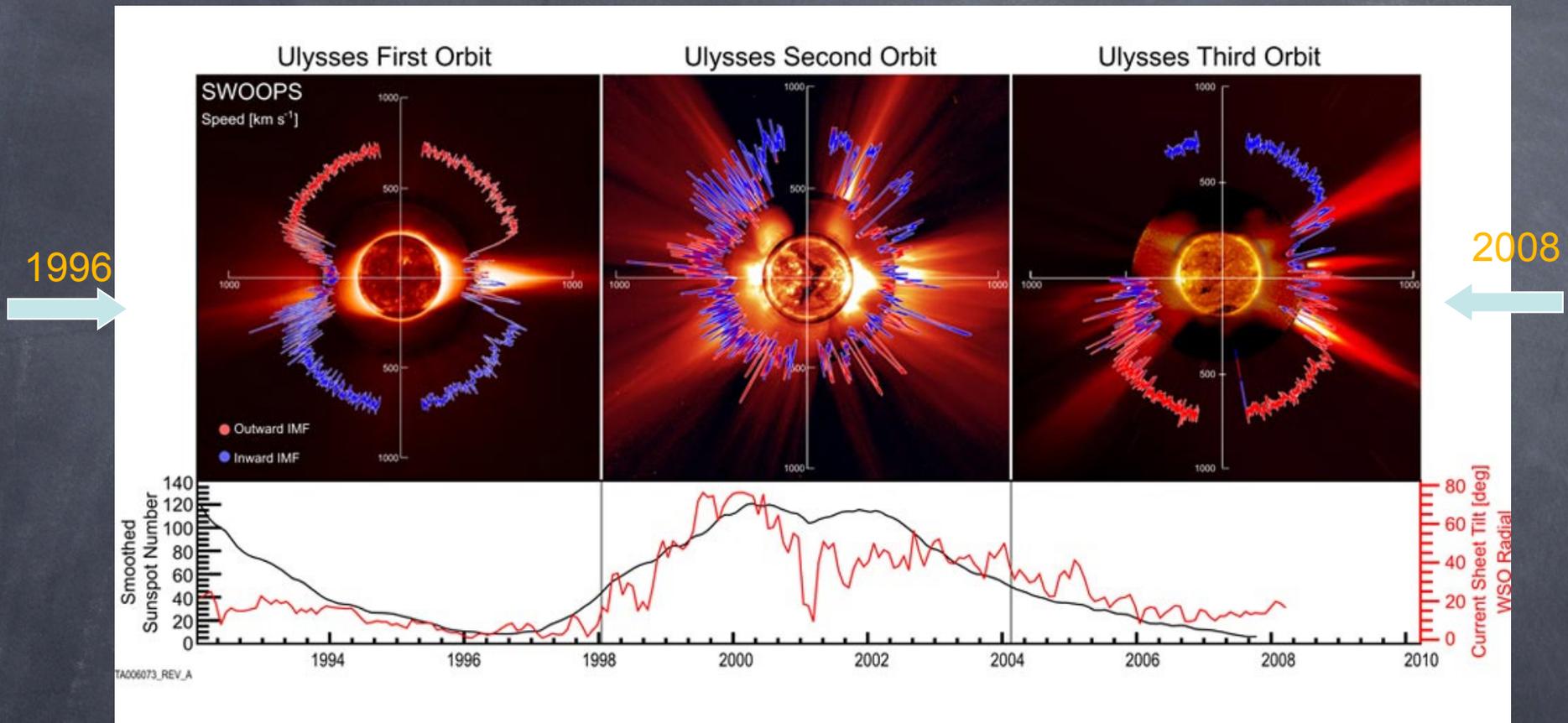


GCRs may influence rate of cloud formation.
Scientists still analyzing influence of clouds on climate
Stay tuned!

Solar Wind from ACE



Solar Wind from Ulysses

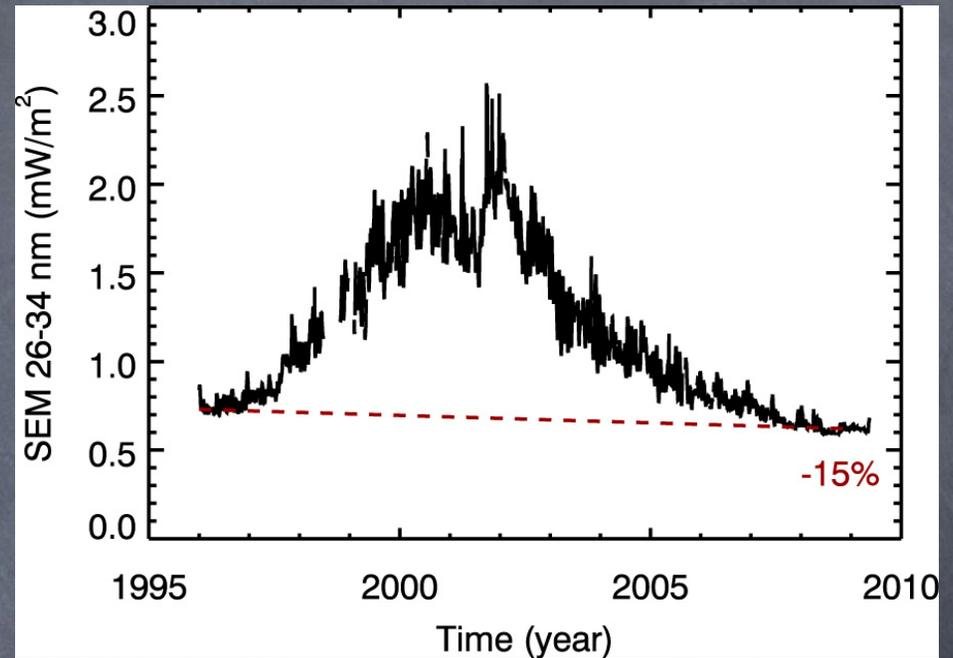


Ulysses measures solar wind out of the plane of the solar system.

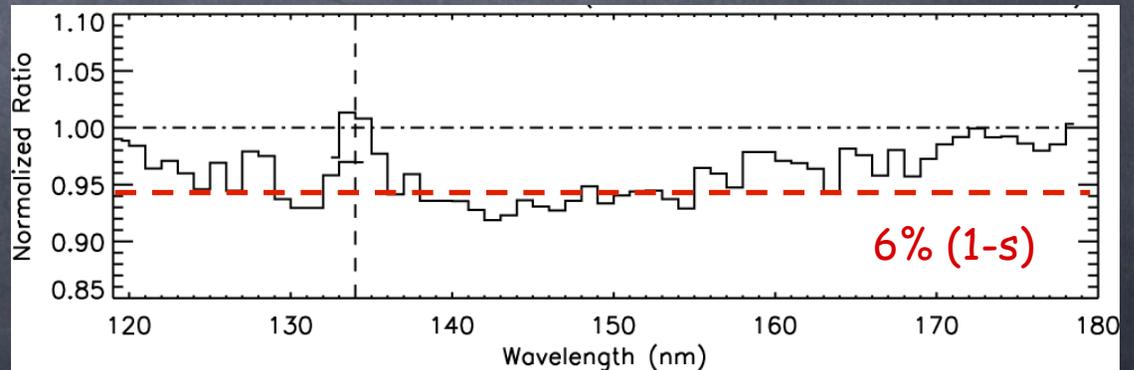
2008 was very different than 1996.

Changes at UV Wavelengths

SOHO SEM 26-34 nm is about 15% less in 2008 than in 1996 (Leonid Didkovsky, '09 SPD 18.07)
Uncertainty is ~6%



SORCE SOLSTICE FUV is about 1-6% less than UARS in 1996 (Marty Snow, '09 SPD 11.12)



These results are not very accurate, just barely larger than the noise.

