If the Sun is so quiet, why is the Earth still ringing?

Sarah Gibson

Talk outline

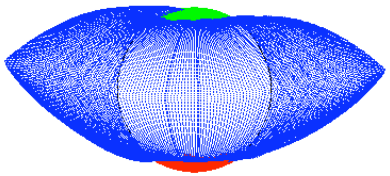
- Overview of differences between current and past solar minima (with extreme bias towards comparison to “space age” cycles!)
    - Case studies: WHI vs WSM (a solar rotation in 2008 vs. one in 1996)
        - How quiet was it at the Earth? (and what do we mean by “quiet”)?
    - How things changed in late 2008/2009
- Implications/new questions raised for Sun and solar wind

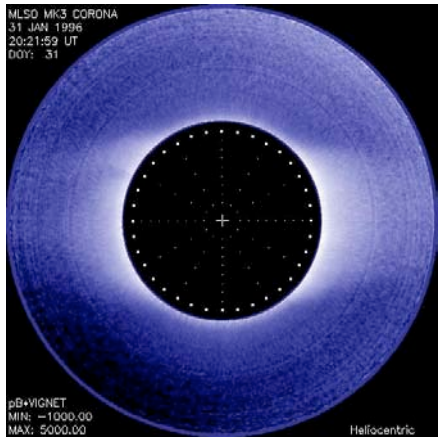
WHI vs. WSM

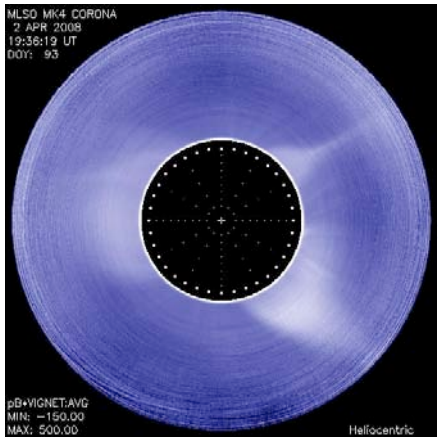
- Two well-studied solar rotations during two solar minima
  - **Whole Sun Month** (August, 1996)
  - **Whole Heliospheric Interval** (March/April, 2008)
- Similar sunspot numbers
- Different morphologies
- Illustrate (some of the) differences between minima (2008 vs. 1996)

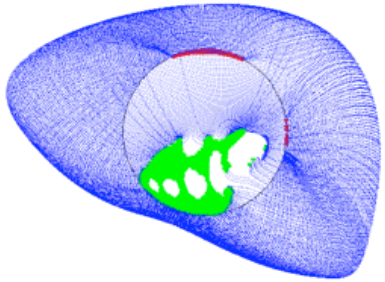
Cycle 22: Whole Sun Month (WSM)

Cycle 23: Whole Heliosphere Interval (WHI)





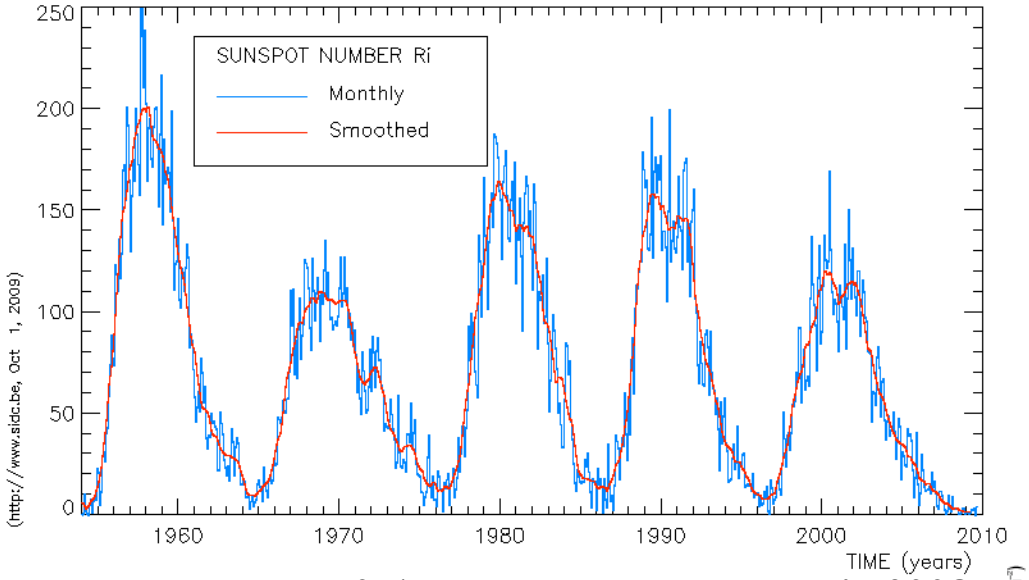




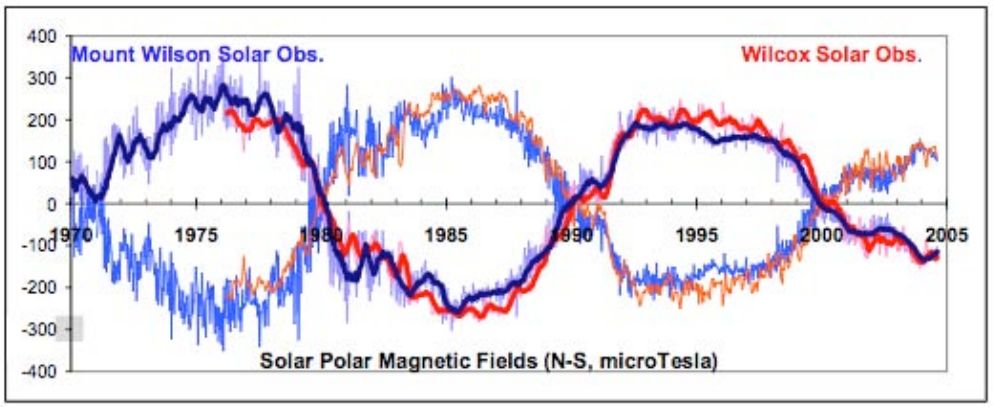
NSO-GONG *HAO/MLSO* *NSO-GONG*

Current solar minimum: **Deep**

Sunspot Number: 2008 had 266 spotless days - most since 1913



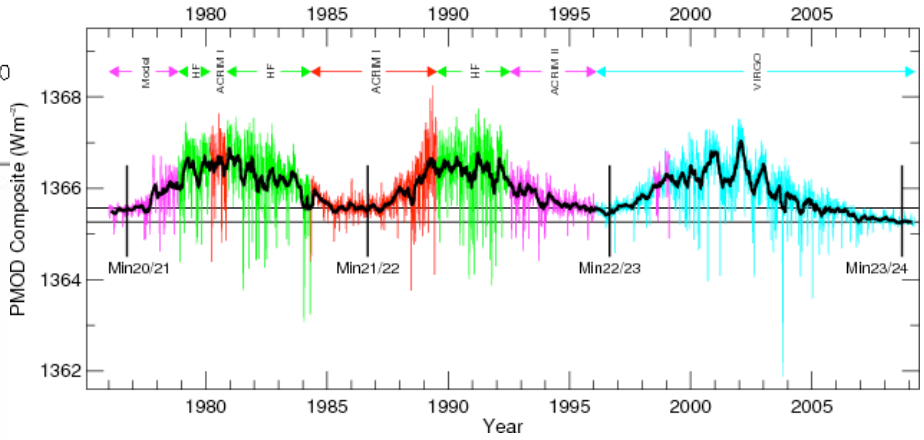
B at solar poles ~40% weaker than last cycle in 2008



Svalgaard et al., GR, 32, 1104, 2005

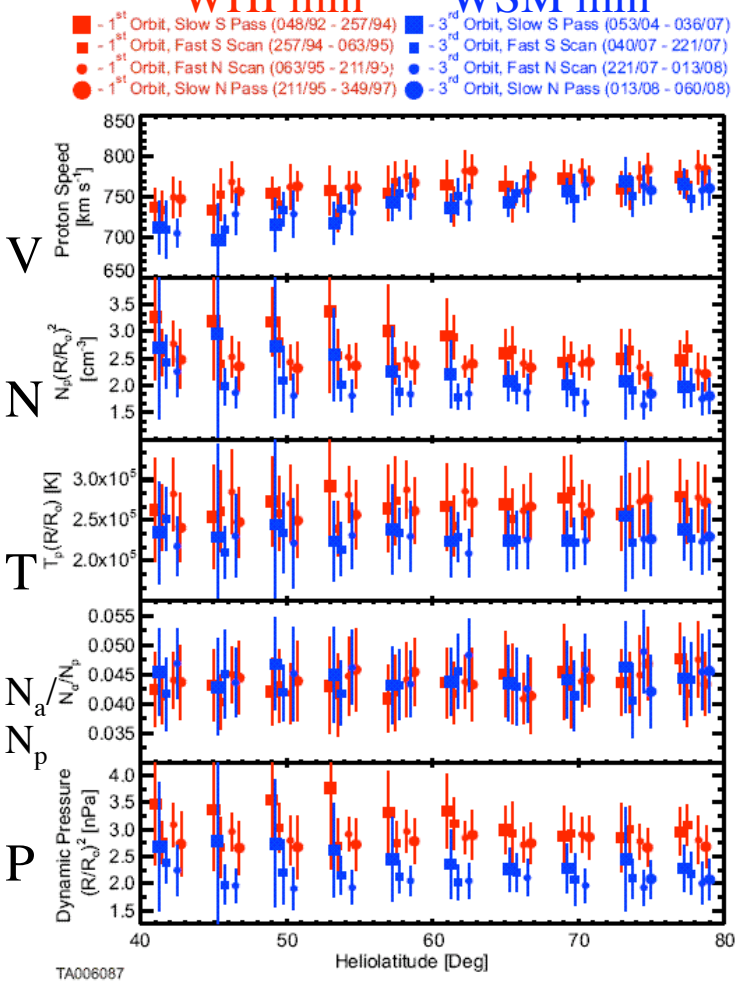
At the sun…

Solar irradiance: 22% depleted relative to past minima (note difference is still small relative to min-max variation)



Froelich, C, A&A, 501, L27, 2009

Current solar minimum: **Deep**



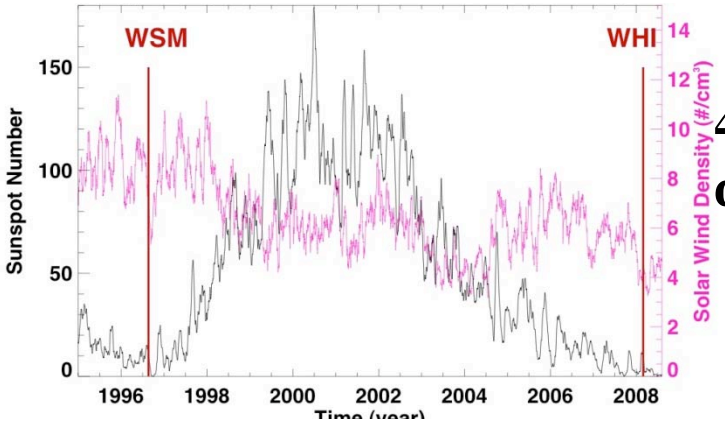
Ulysses during **polar** passes: lower magnetic field (35%), density (20%), speed (3%)

McComas et al., GRL, 35, L18103, 2008

In the solar wind…

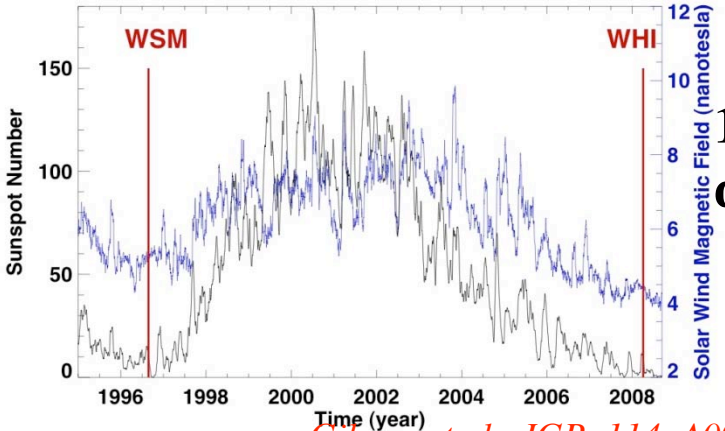
OMNI **near-ecliptic** solar wind: density decreased 45%; magnetic field 15%

N



45% decrease

B



15% decrease

Gibson et al., JGR, 114, A09105, 2009

Current solar minimum: **Deep**

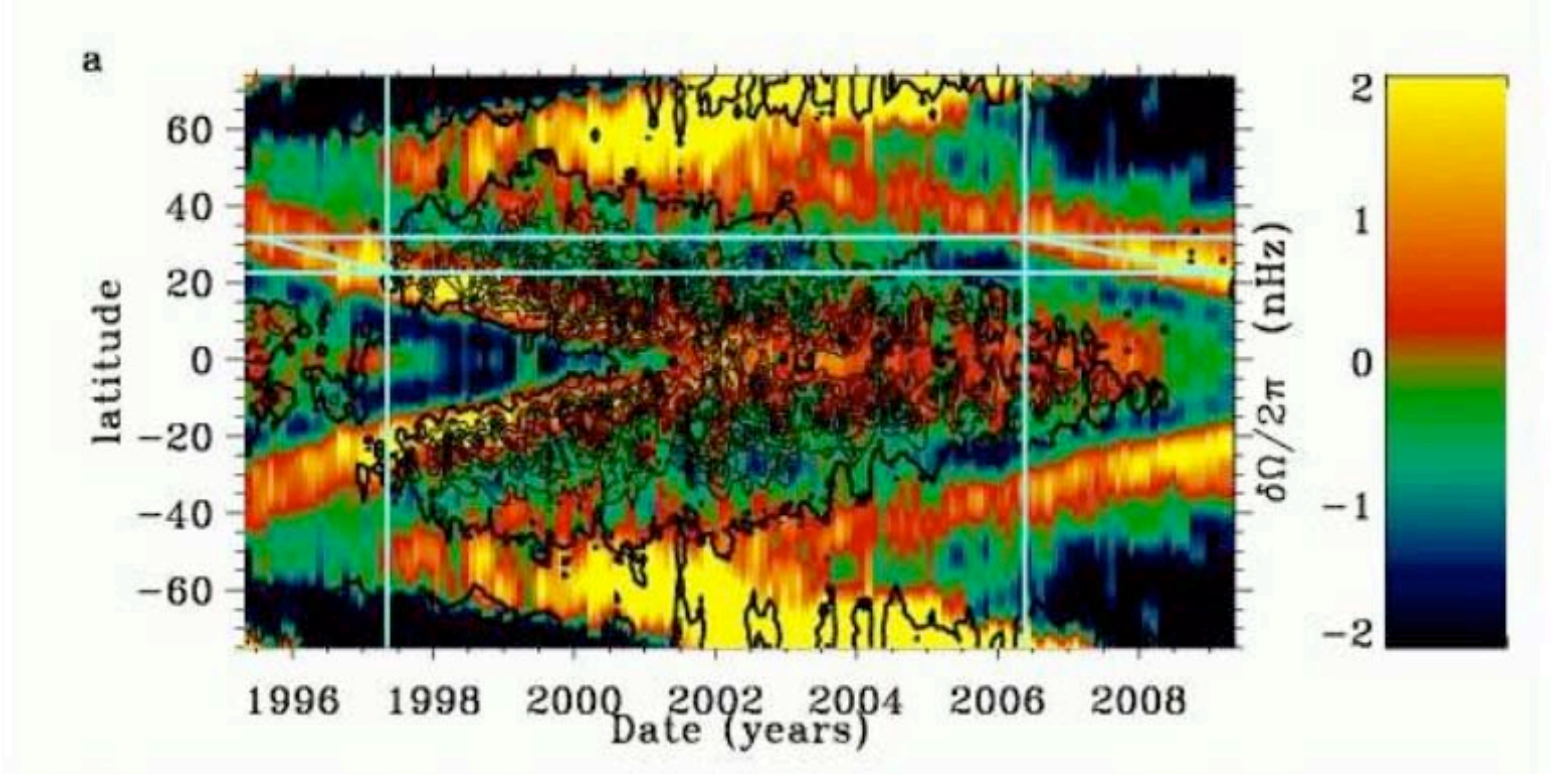
At the Earth…

Getty images

Earth's ionosphere thin and cool

Space "closer than you think" by about 100 miles (NASA-CINDI)

Current solar minimum: **Long**



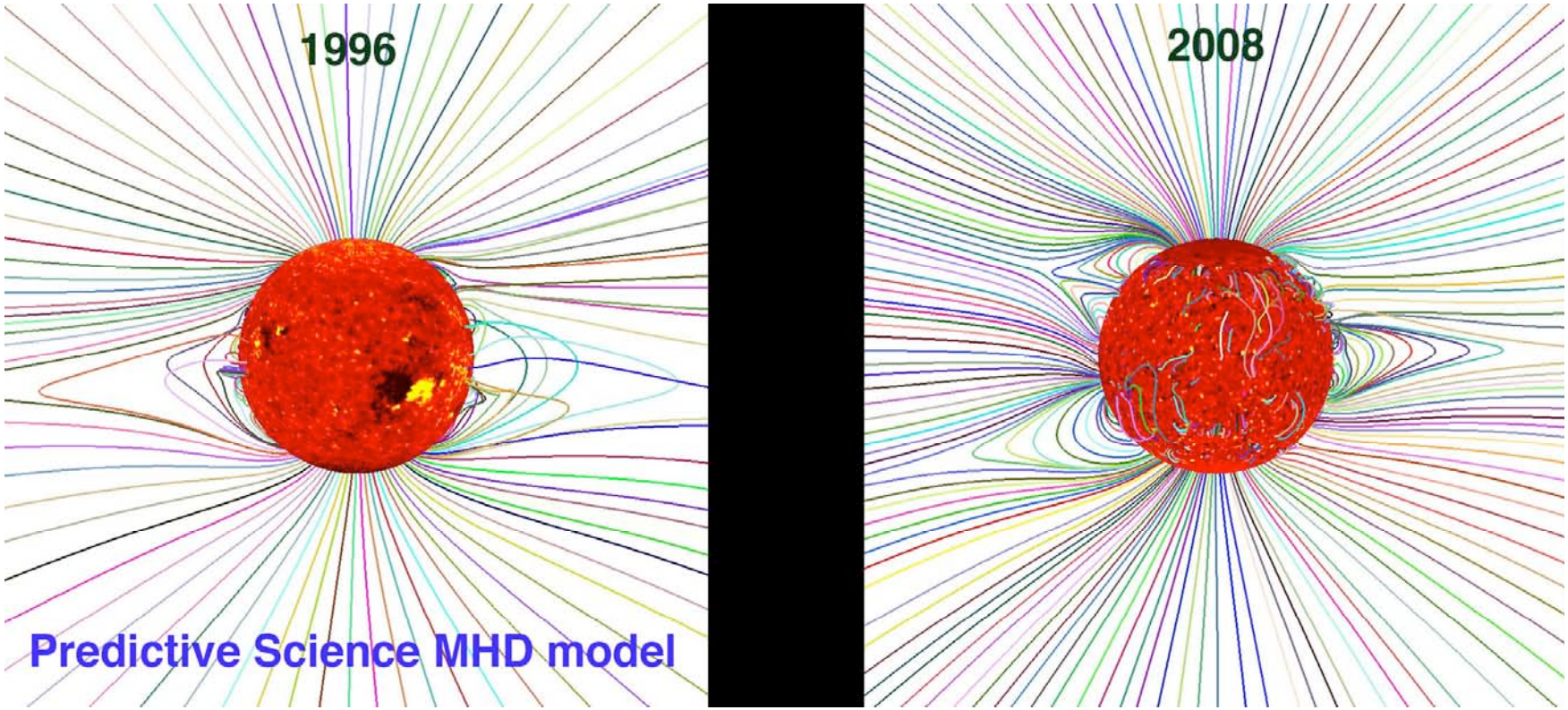
Howe et al., ApJ, 701, L87, 2009

Solar sub-surface flows evolving slowly

Trend towards equator of relatively fast (red/yellow) flows has a shallower slope

Current solar minimum: **Complex**

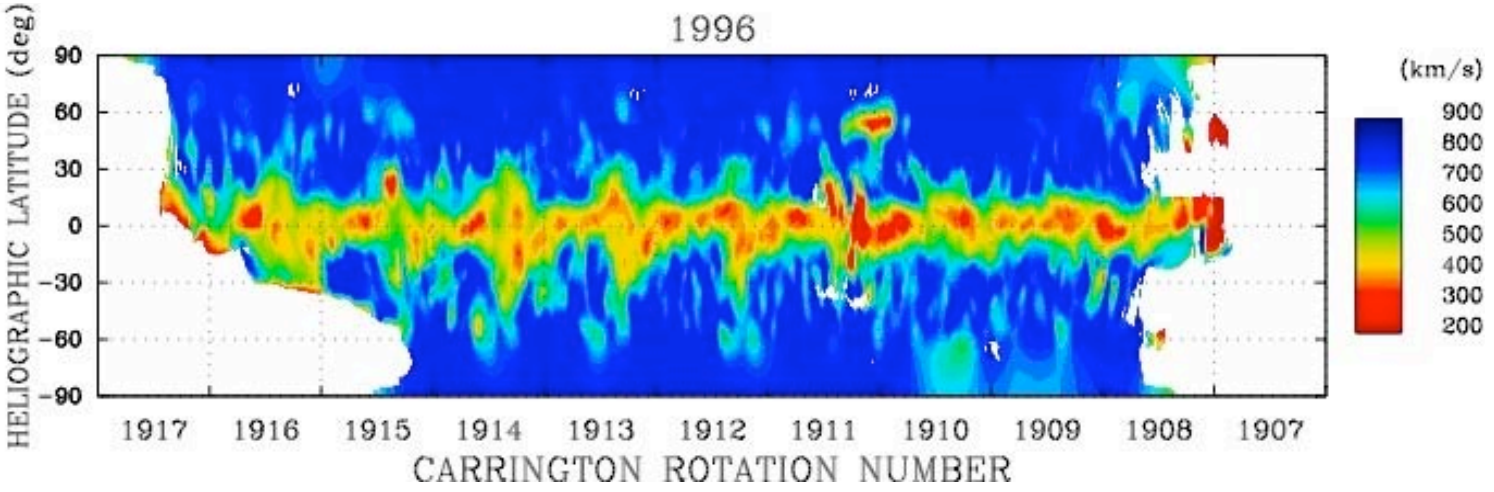
More open magnetic flux at low latitudes in 2008 than in 1996.



Current solar minimum: **Complex**

Fast wind threads the ecliptic more commonly in 2008 than 1996.

Solar wind velocity from STEL interplanetary scintillation data



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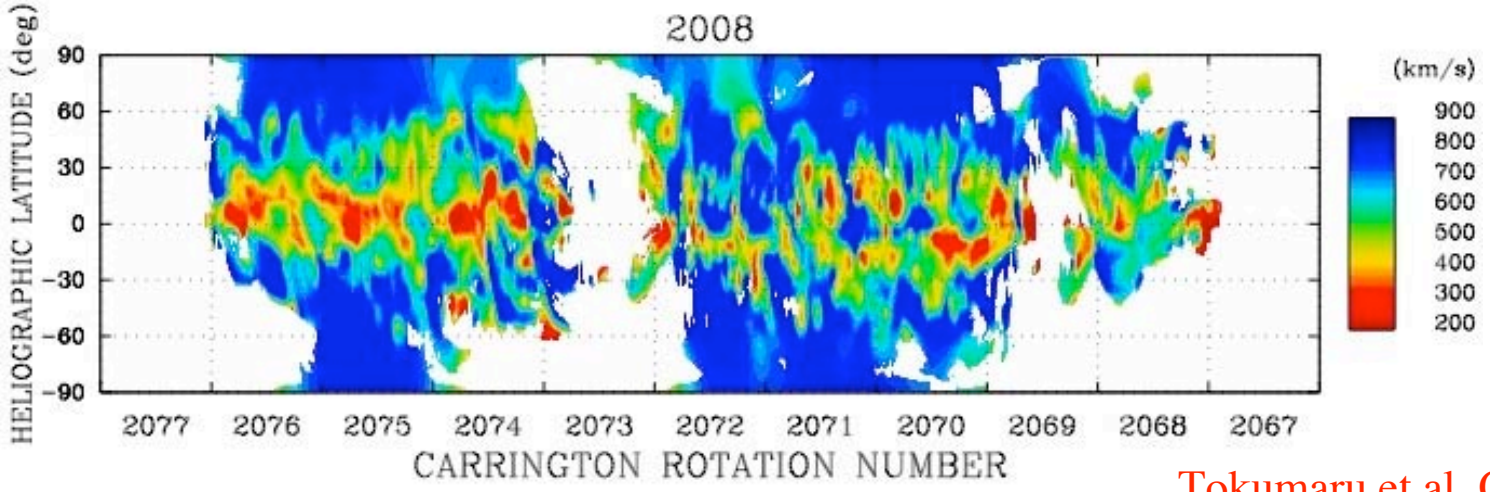
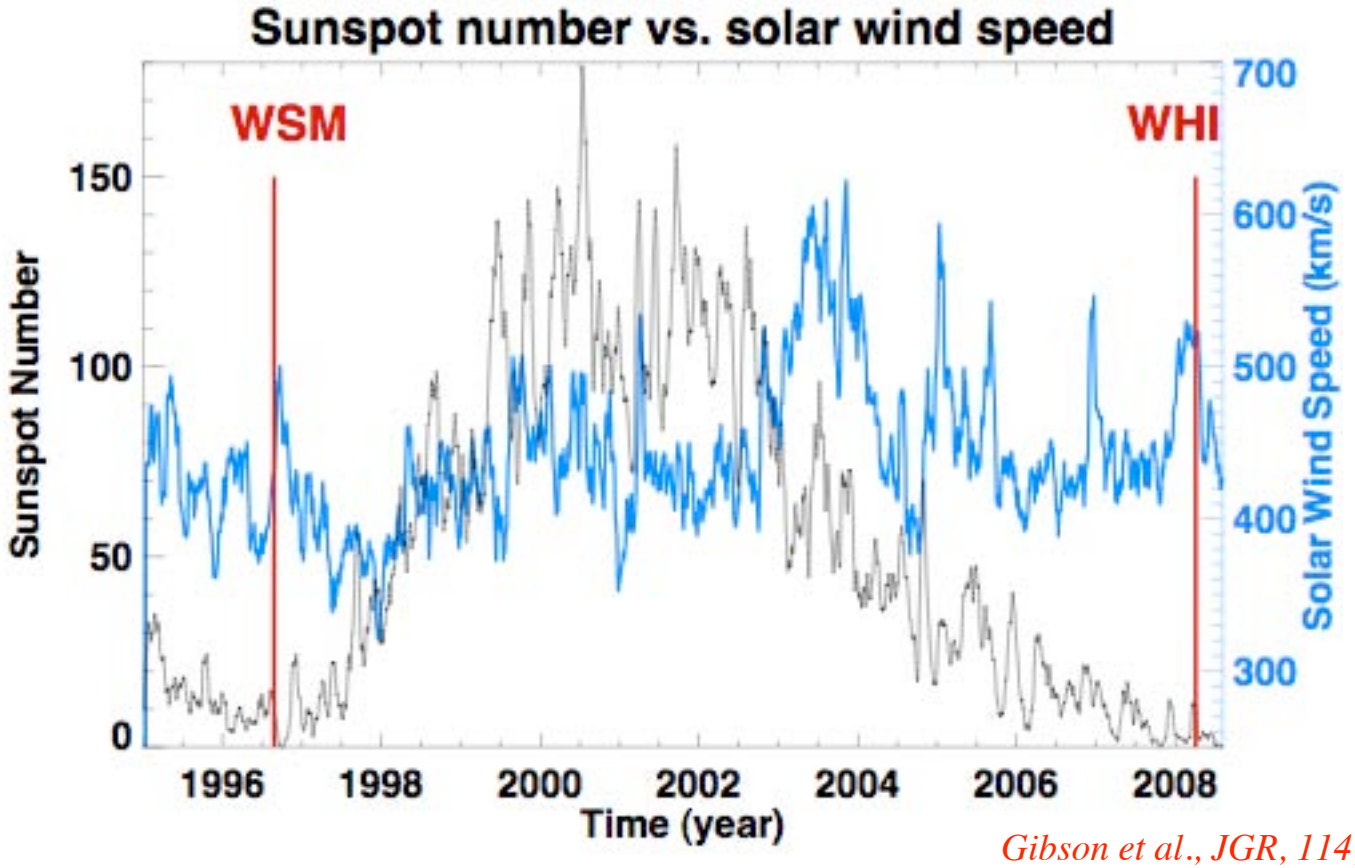


Tokumaru et al, GRL, 36, 9, 2009

Current solar minimum: **Complex**

OMNI **near-ecliptic** solar wind speed: increased due to high-speed streams (HSS)



Gibson et al., JGR, 114, A09105, 2009

13% increase in V at Earth! WSM 31% in HSS; WHI 59% in HSS

So was the Earth quiet in 2008? Yes, and no (depends what you look at).

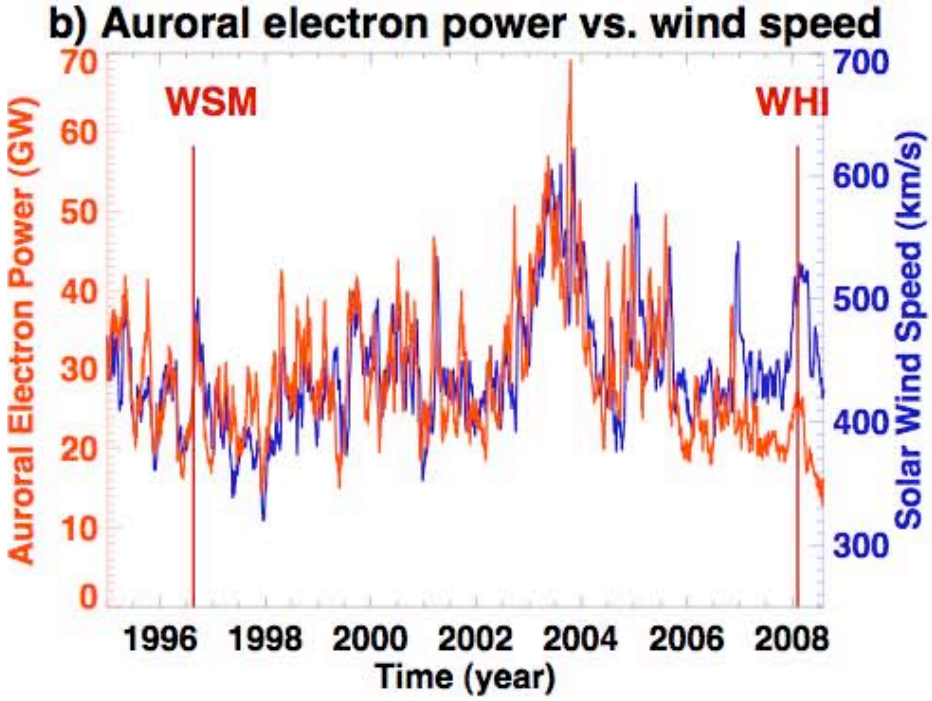
Auroral power lower

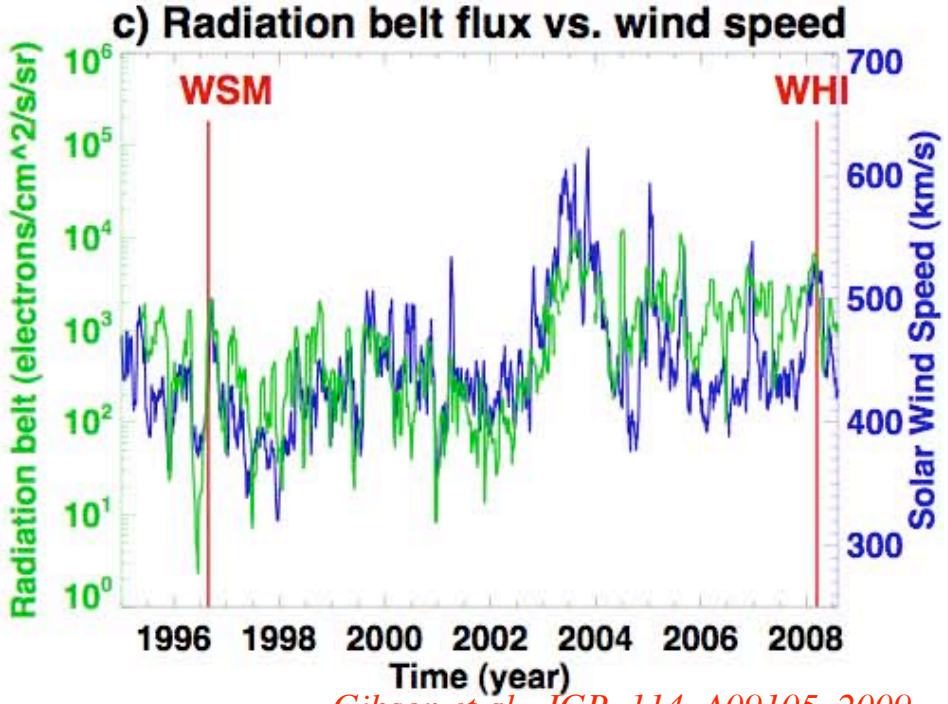
- **10% decrease** for WHI vs. WSM (lower magnetic field in the solar wind)

But relativistic electrons in outer radiation belt (GOES geosynchronous) pumped up

- **340 % increase (71% log)** for WHI vs. WSM (faster wind)

Both depend on both V and B- but in different ways

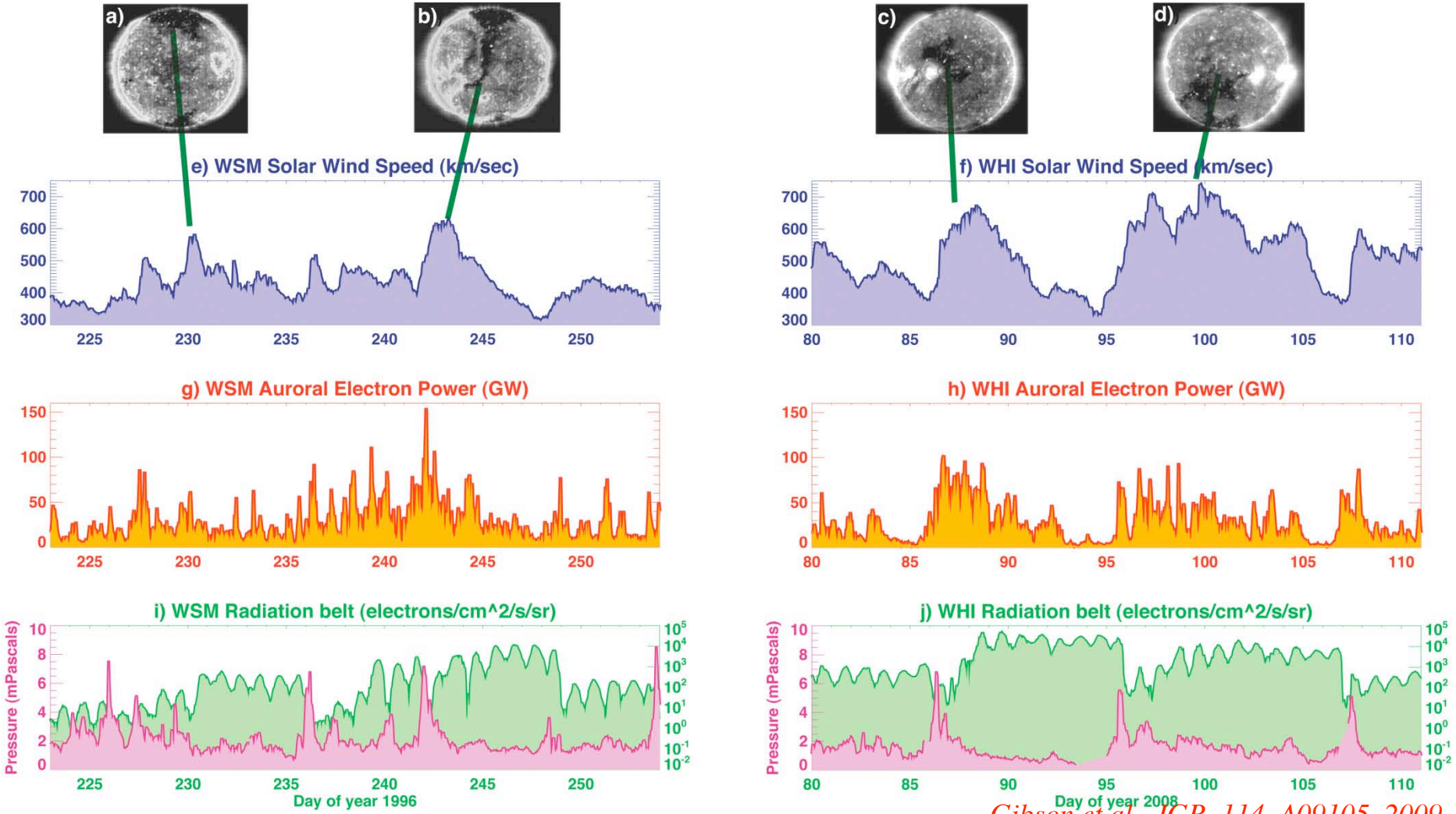




Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

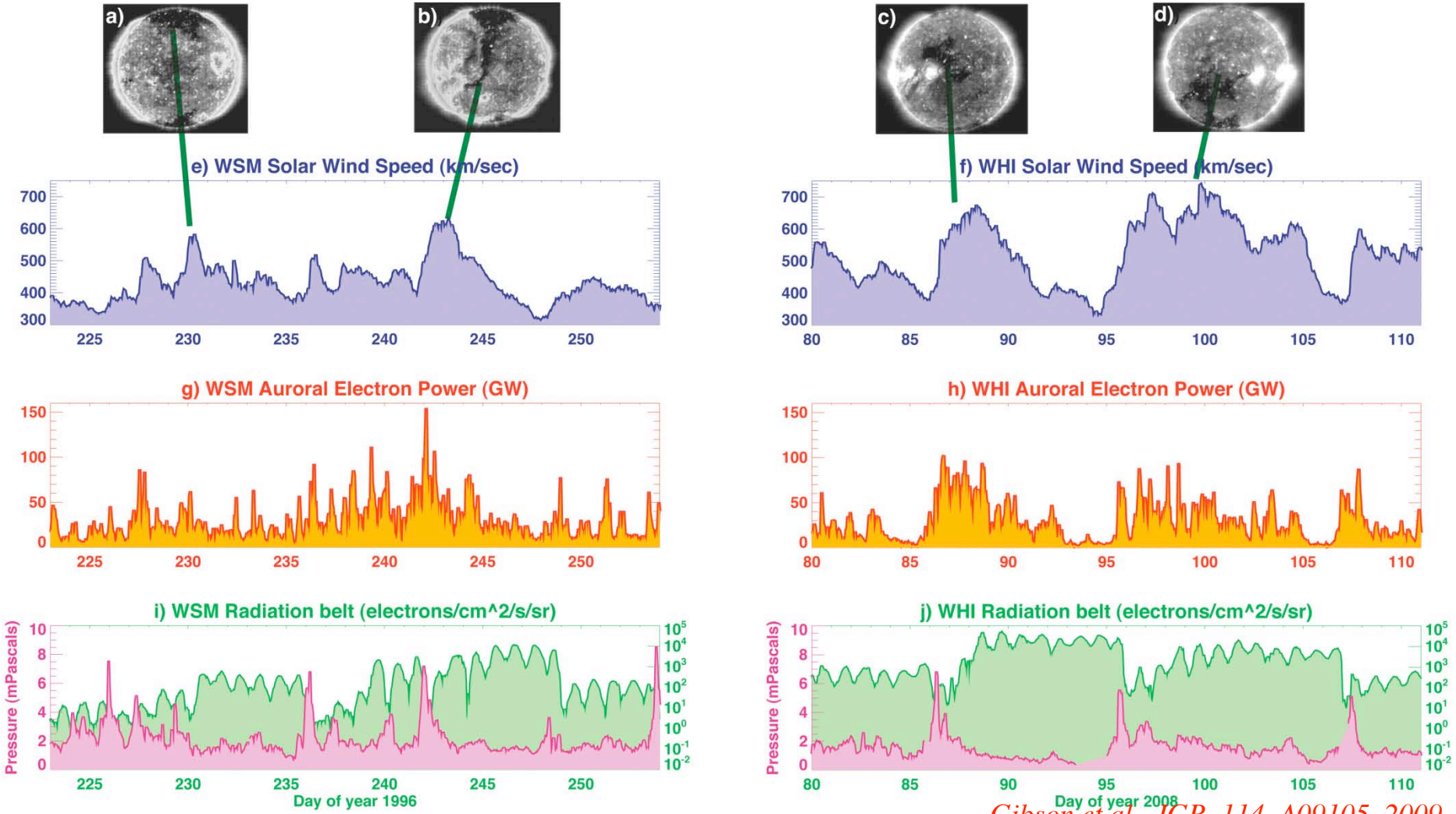
To understand Earth-Sun system, we consider WSM and WHI solar rotations side-by-side.



Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

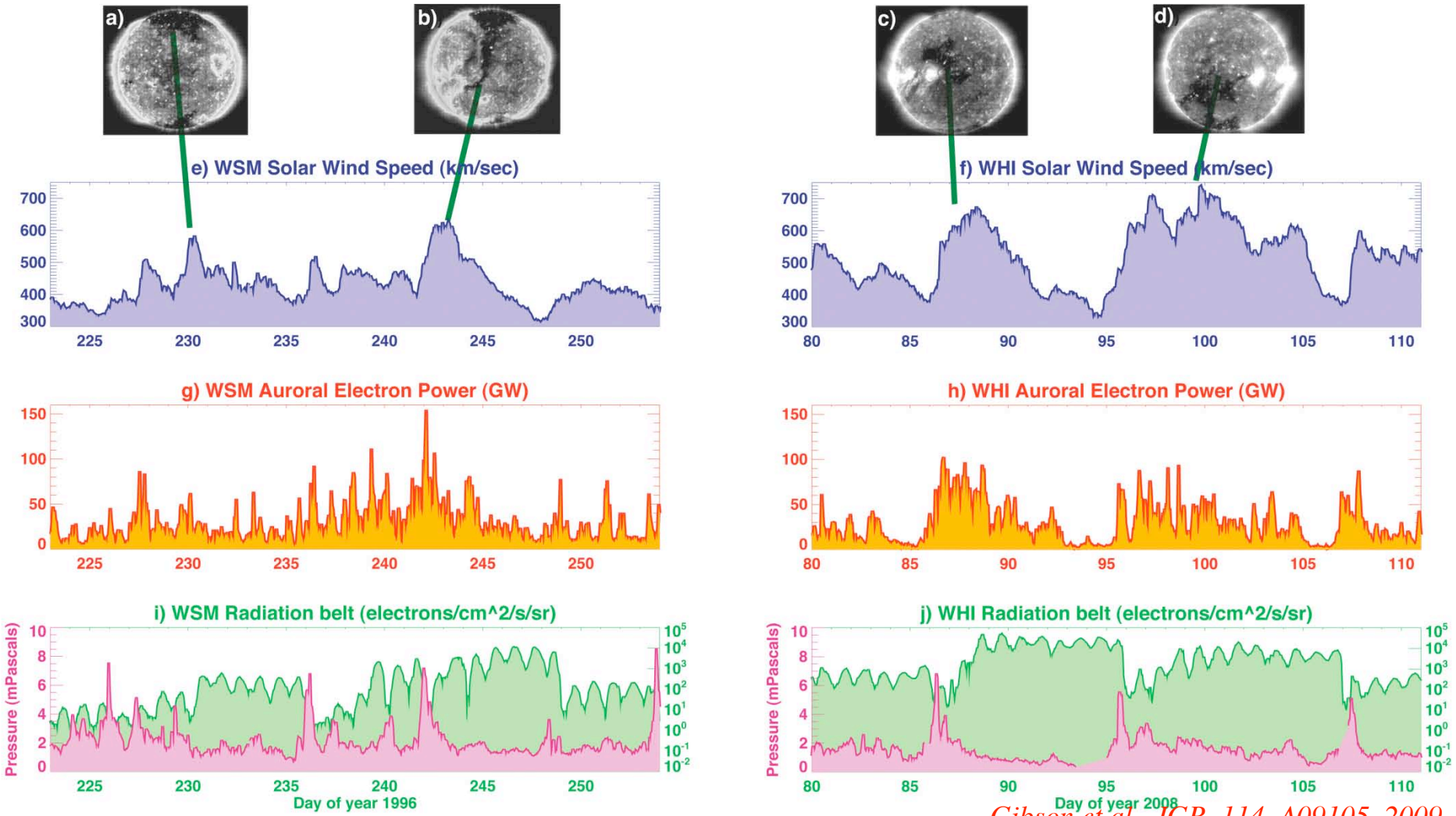
Low-latitude coronal holes -> high-speed streams -> enhanced aurora -> enhanced radiation belt



Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

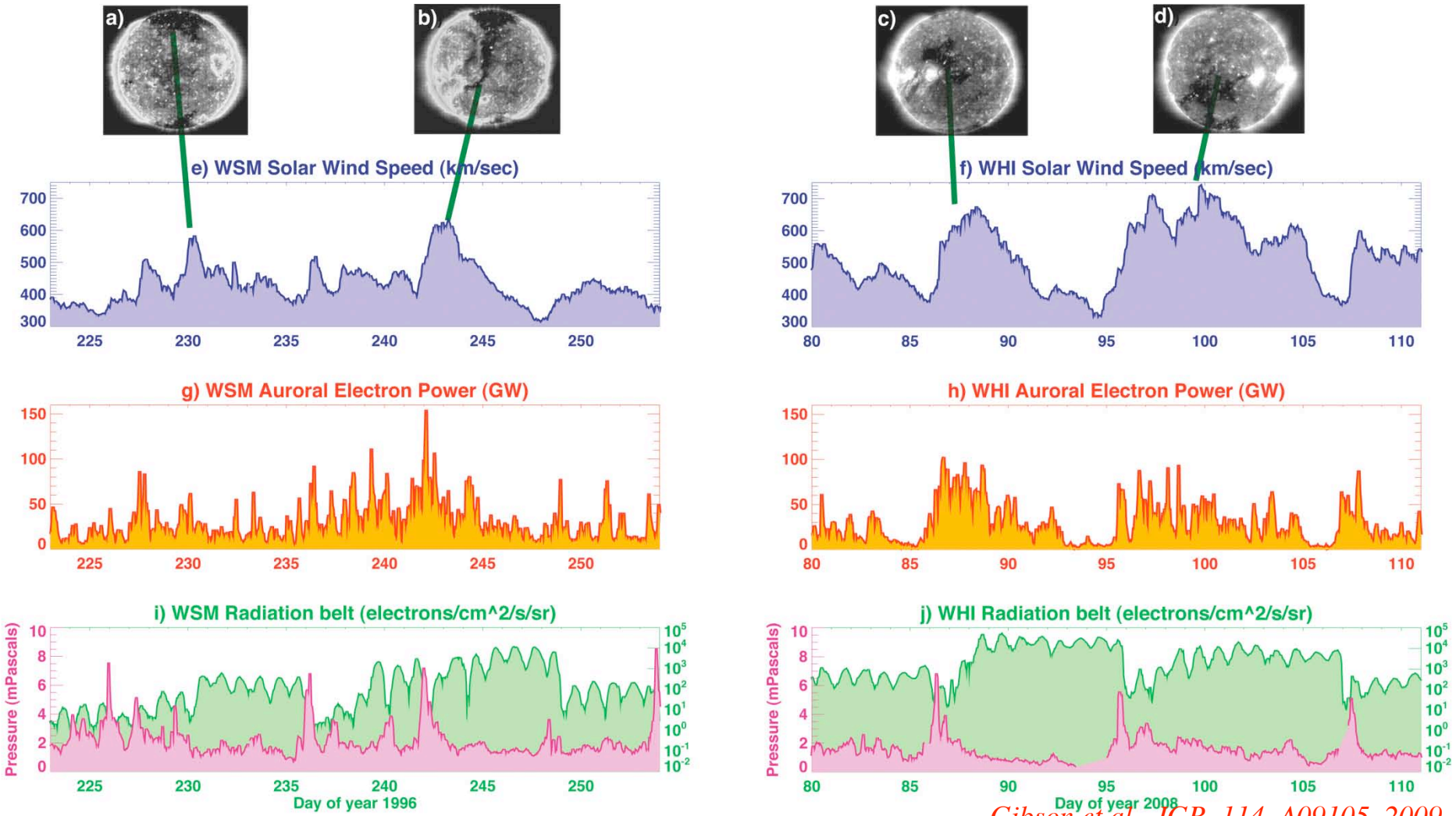
Auroral power correlates to B*V



Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

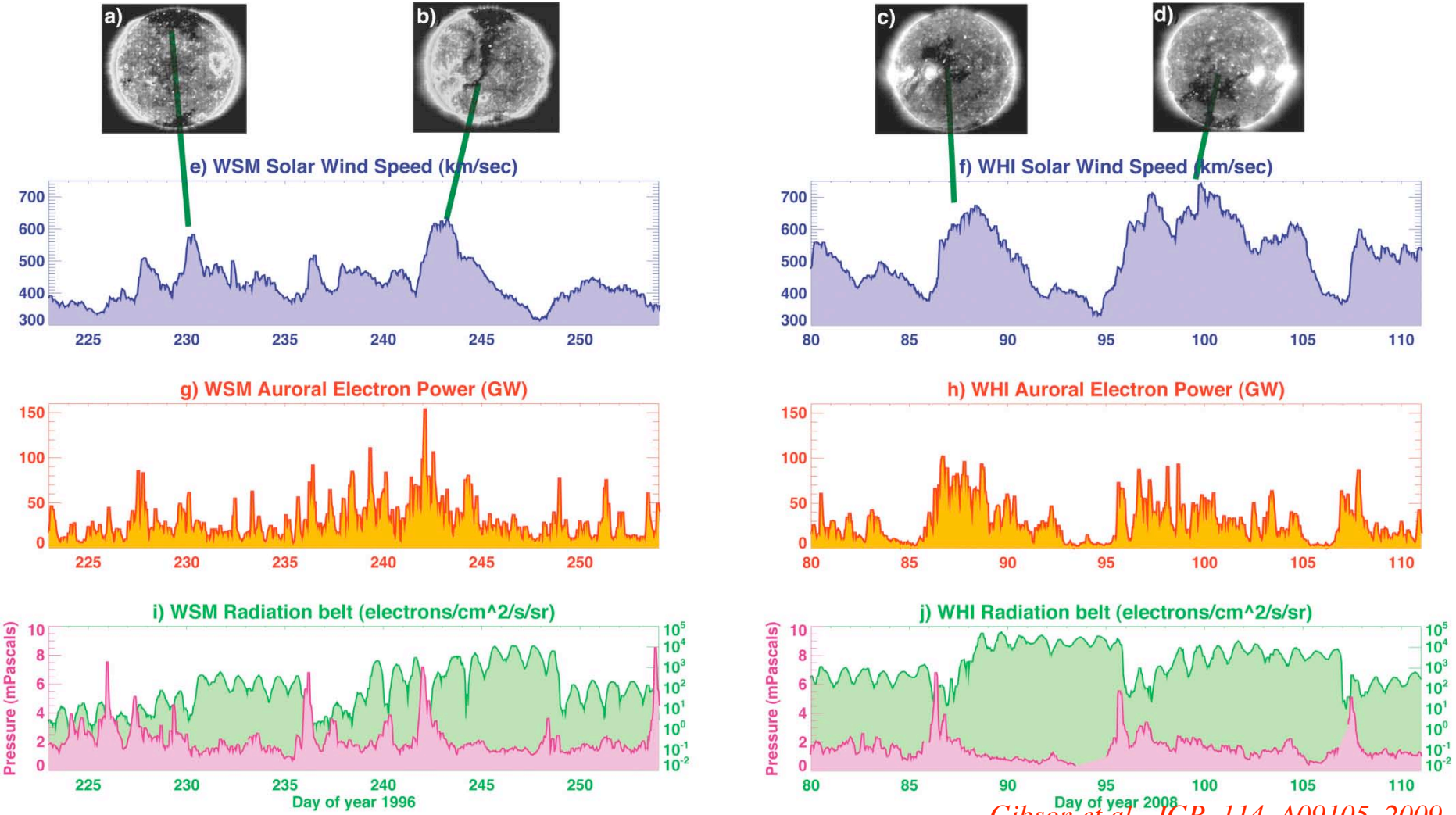
Solar wind primary driver of radiation belt (1-2 day lag)



Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

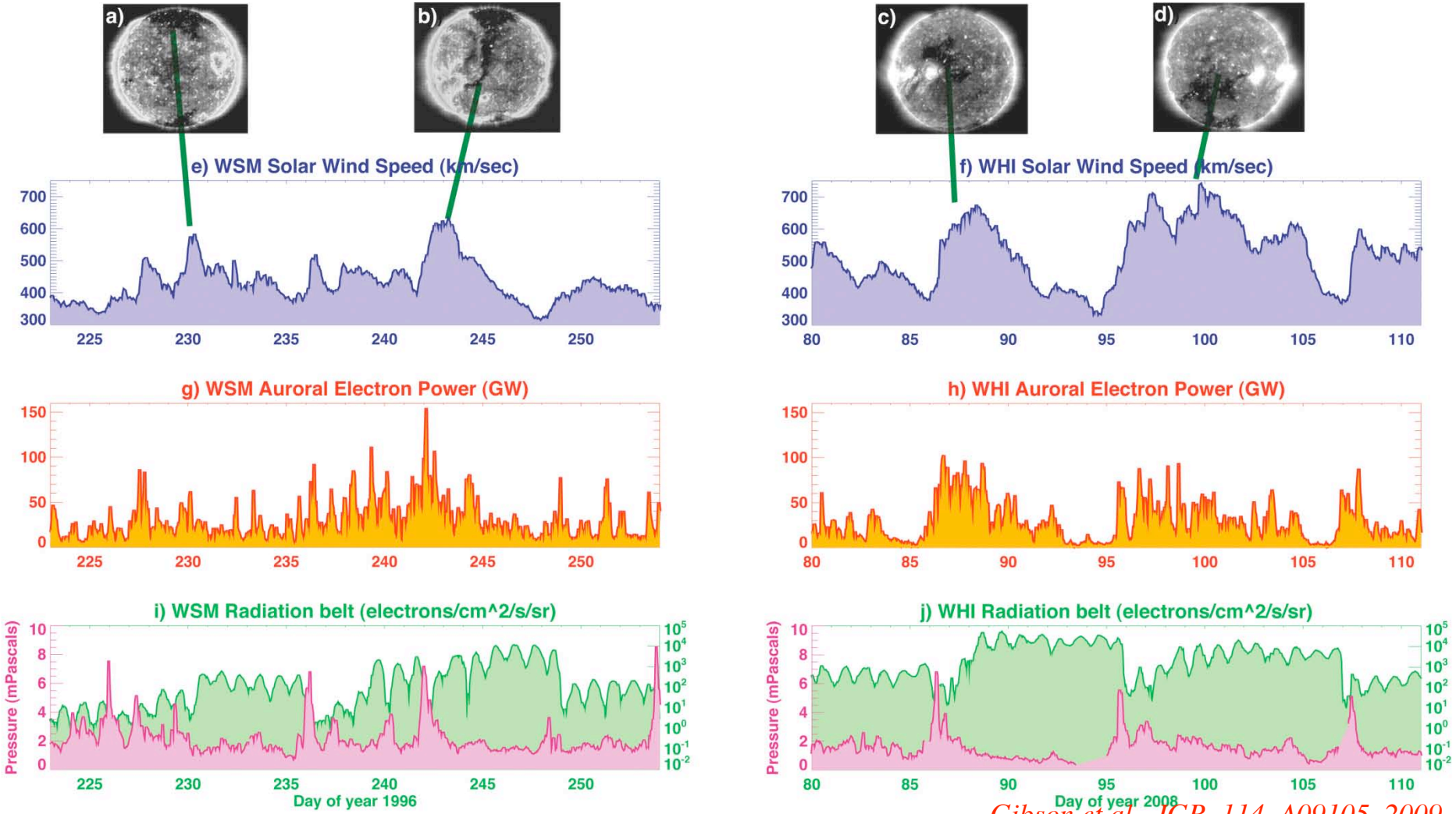
WHI: longitudinally-extended coronal holes -> long and strong HSS



Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

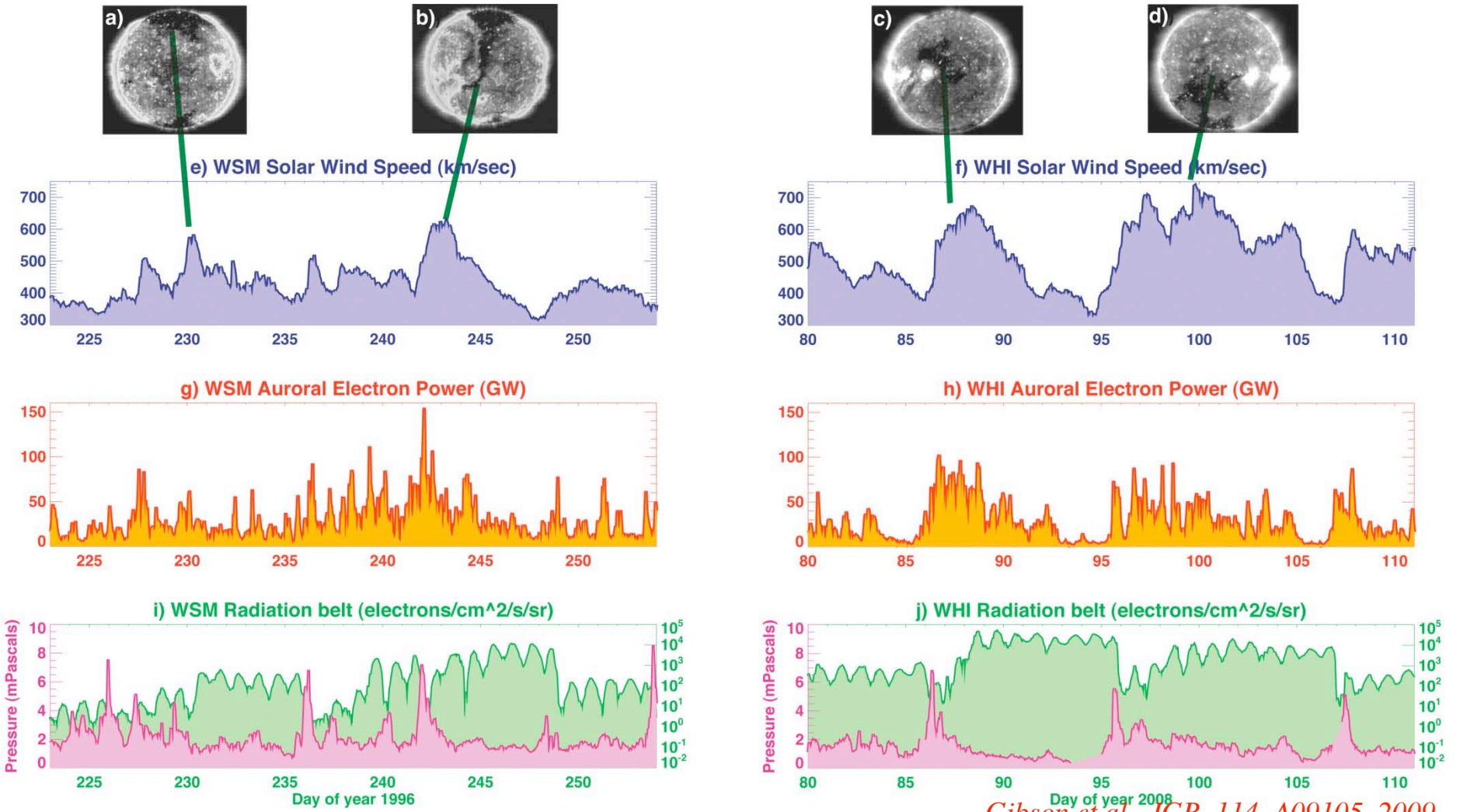
WHI: Long and strong HSS --> clearly modulated aurora



Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

WHI: Long and strong HSS --> clearly modulated and enhanced radiation belt



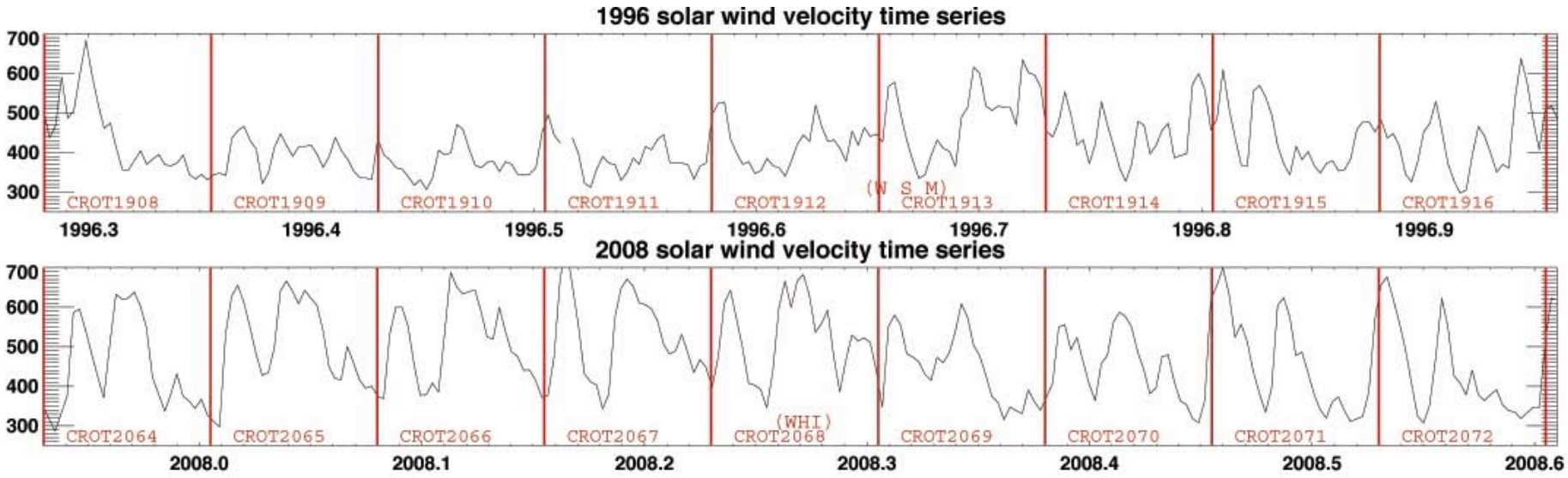
Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

Because sun is rotating, HSS coming from long-lived magnetic structures recur.

This results in periodic solar wind peaks.

More common for the rotations around WHI than WSM.



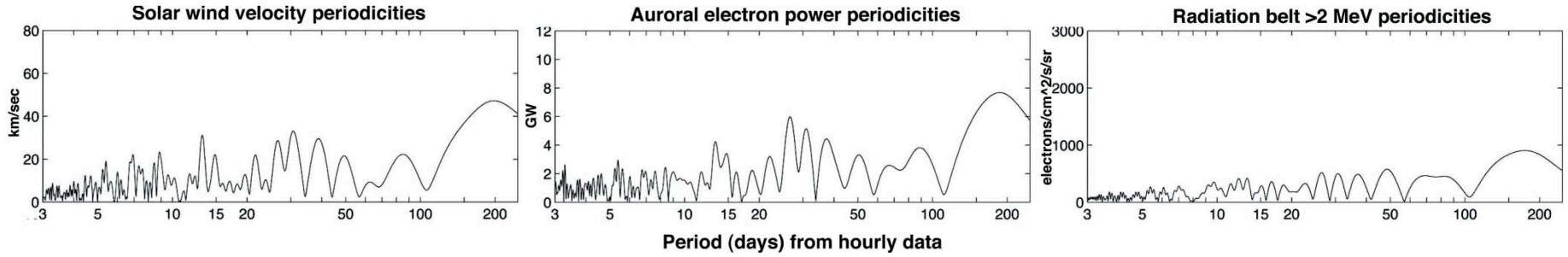
Gibson et al., JGR, 114, A09105, 2009

WHI vs WSM

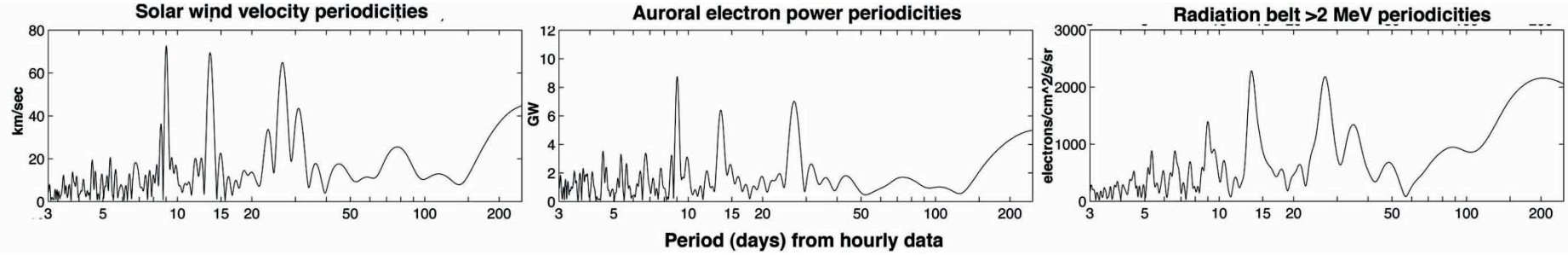
Periodicities (9, 13, 27 day) seen in wind, but also in aurora and radiation belt for WHI

The Earth is ringing

WSM



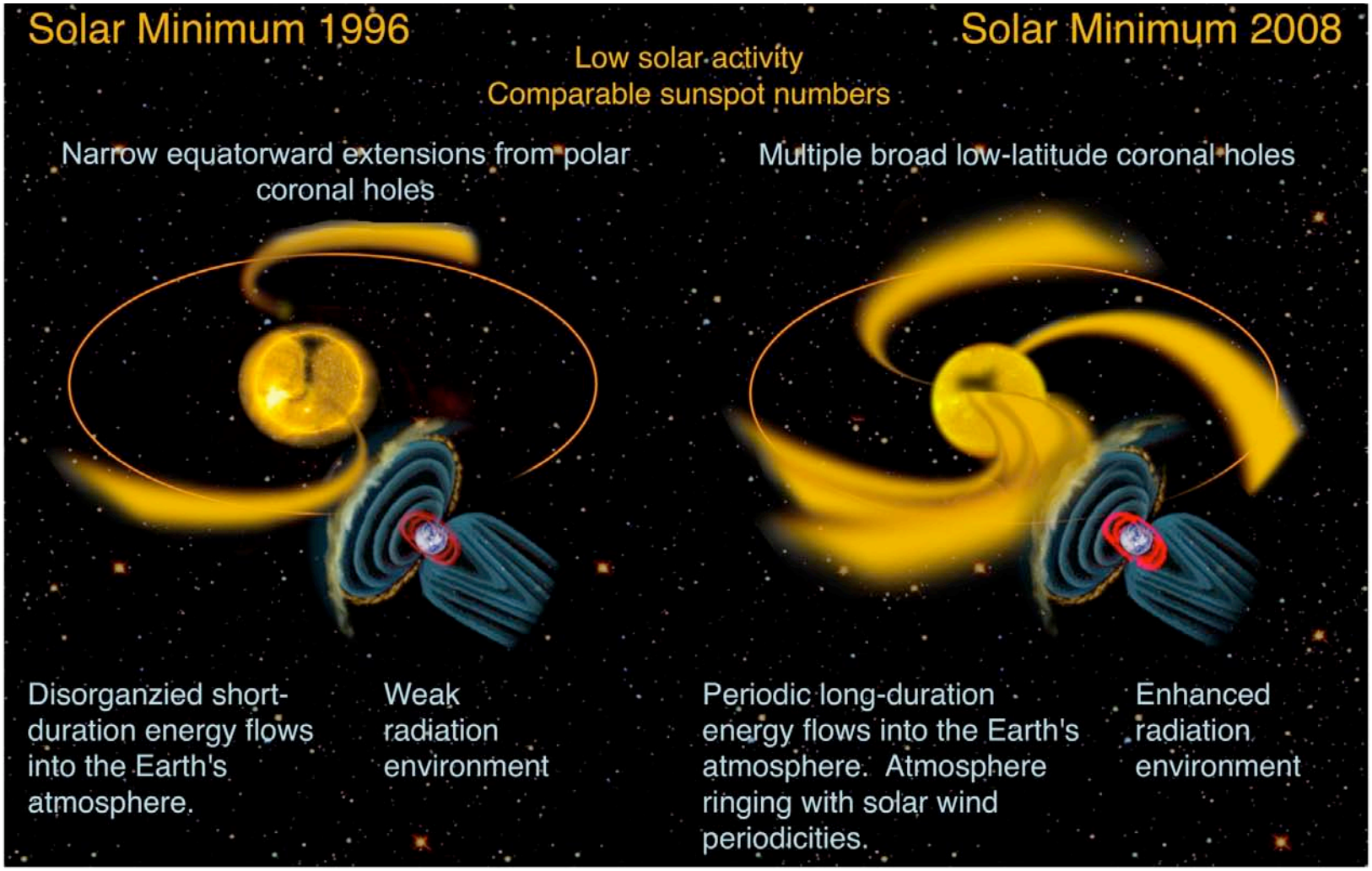
WHI



Gibson et al., JGR, 114, A09105, 2009

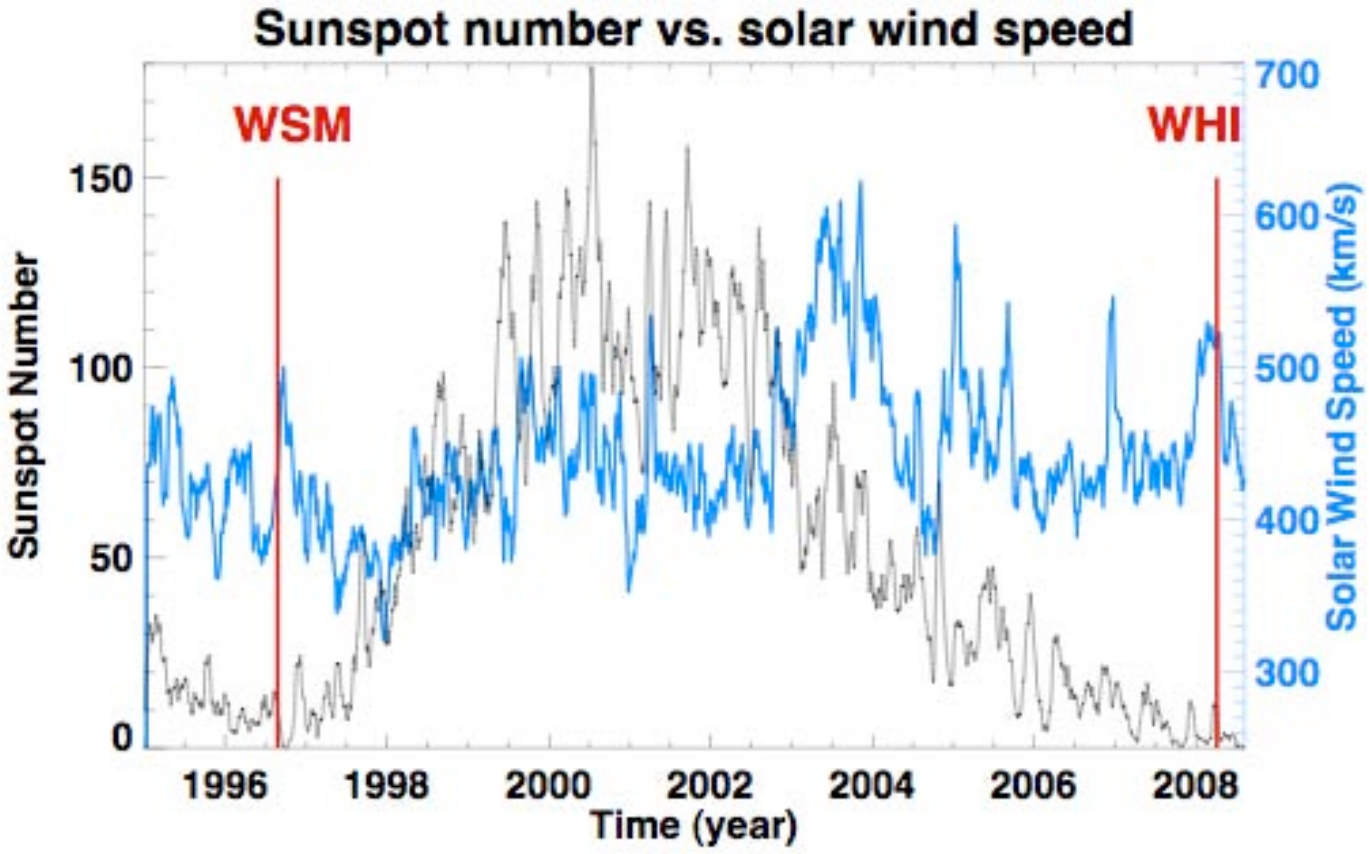
Sunspot number doesn't tell the whole story

…tells us about the depth and length, but not the complexity



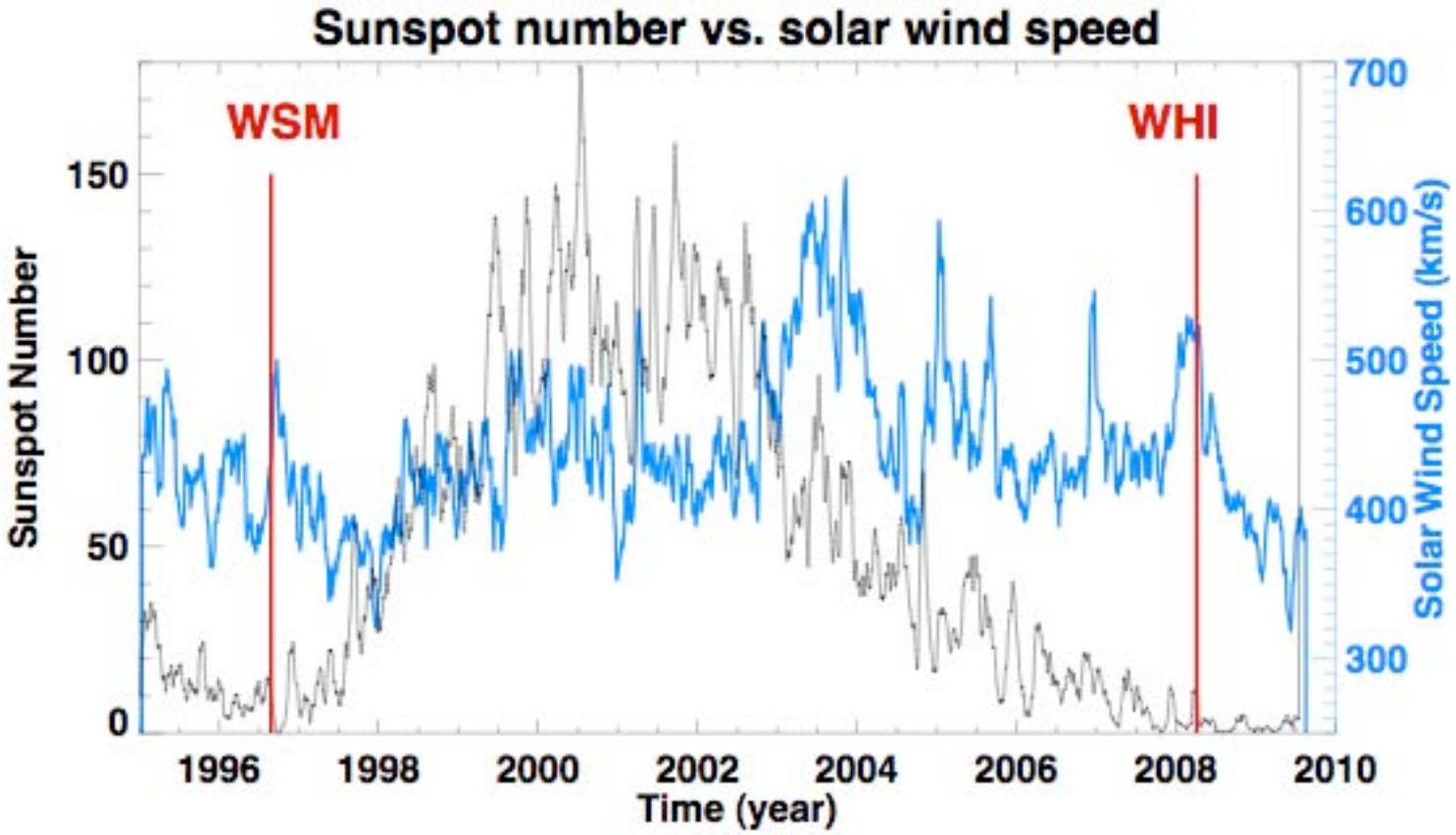
Gibson et al., JGR, 114, A09105, 2009

The story continues… 2009!

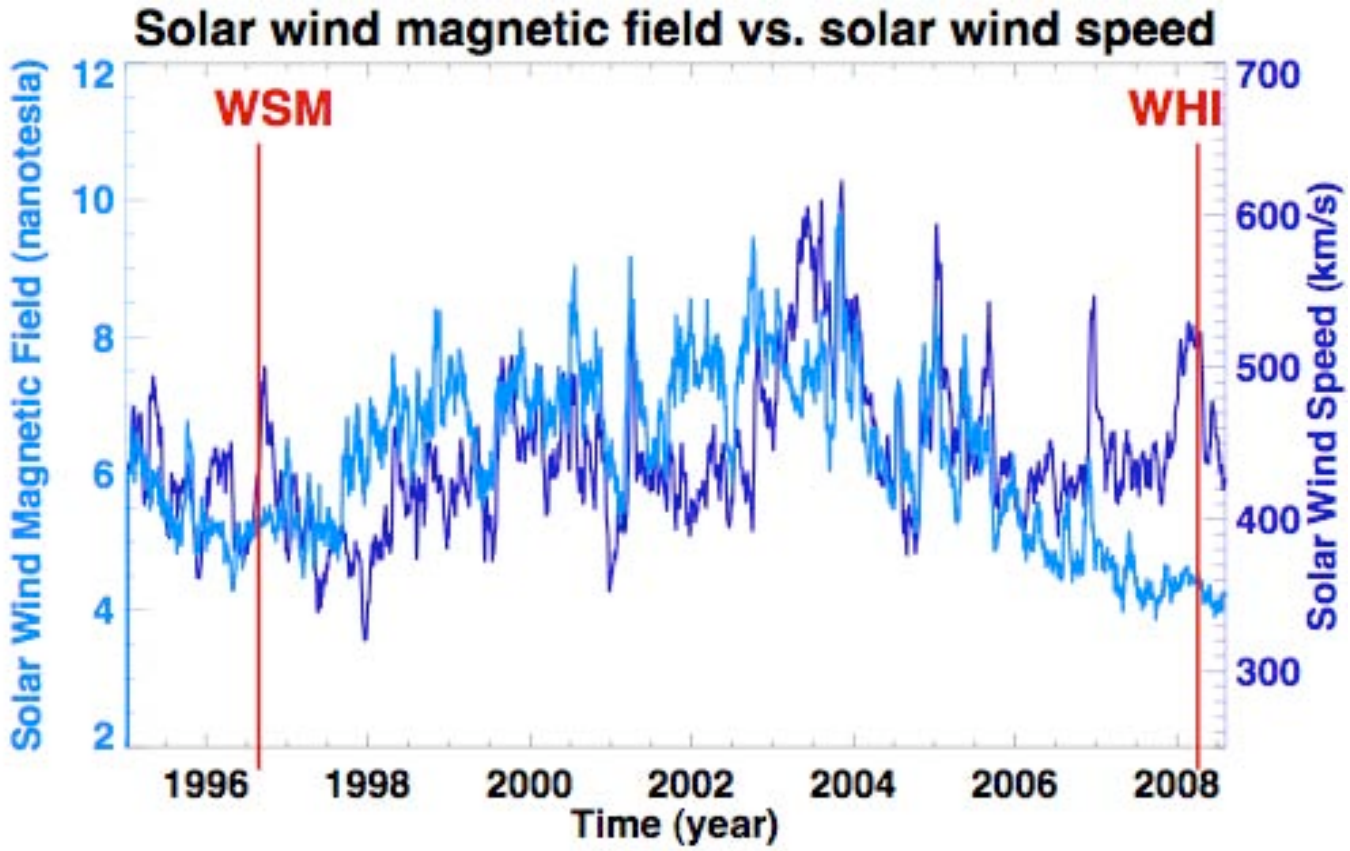


The story continues… 2009!

Velocity takes a dive



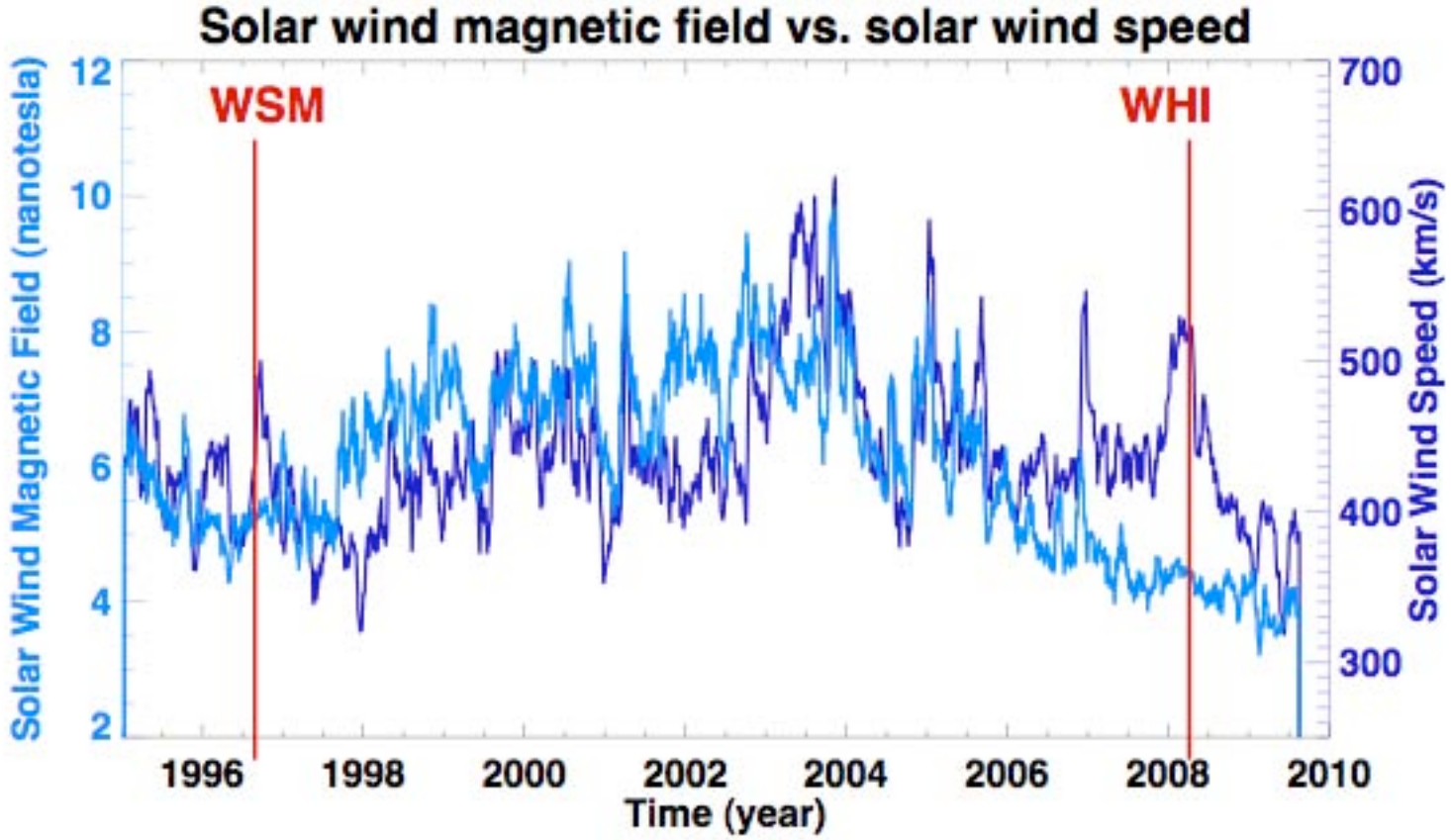
The story continues… 2009!



The story continues… 2009!

~2 year LAG between magnetic field drop and wind speed drop.

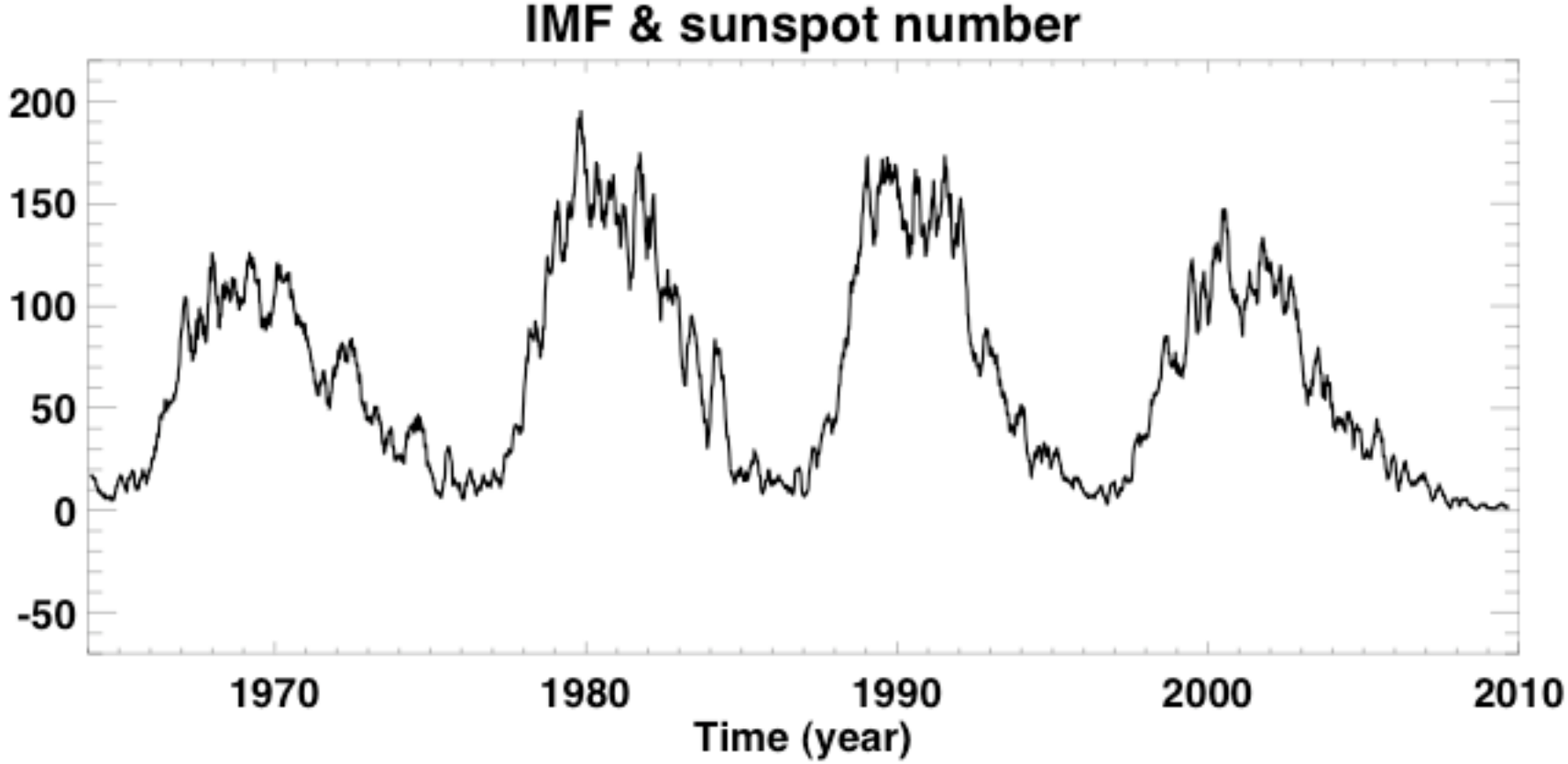
- Allows us to study physical drivers (B and V) "separately" at the Earth



The story continues… 2009!

Sunspot number tells us about magnetic flux emergence

- The more sunspots, the more solar activity and irradiance
- Can't get any lower than zero (no more emerging flux, no new information)

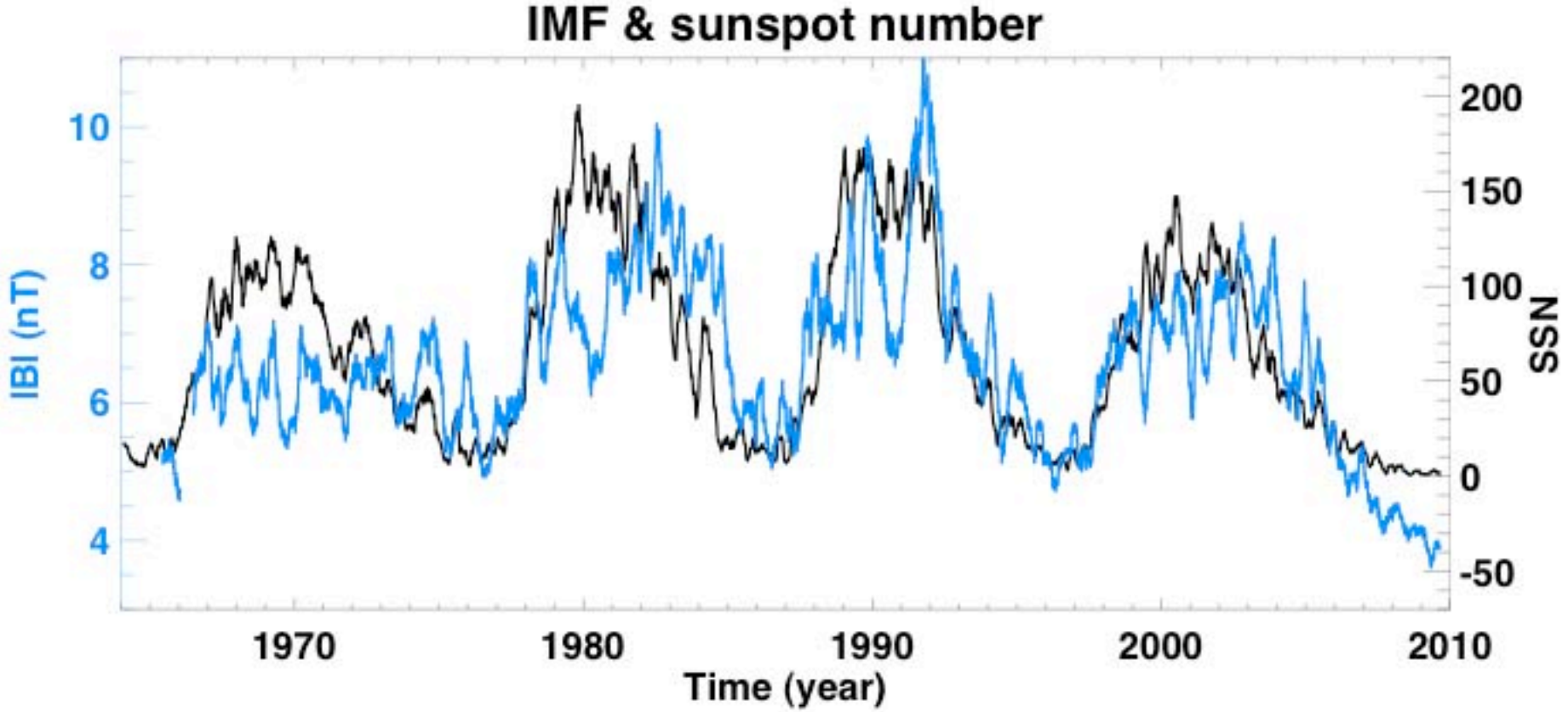


NOAA-NGDC sunspot and OMNI solar wind data (plot created by de Toma)

The story continues… 2009!

Solar wind interplanetary magnetic field (IMF) tells us about "open" solar magnetic flux

- Generally tracks sunspot cycle
- Also depends upon the evolution of open magnetic flux

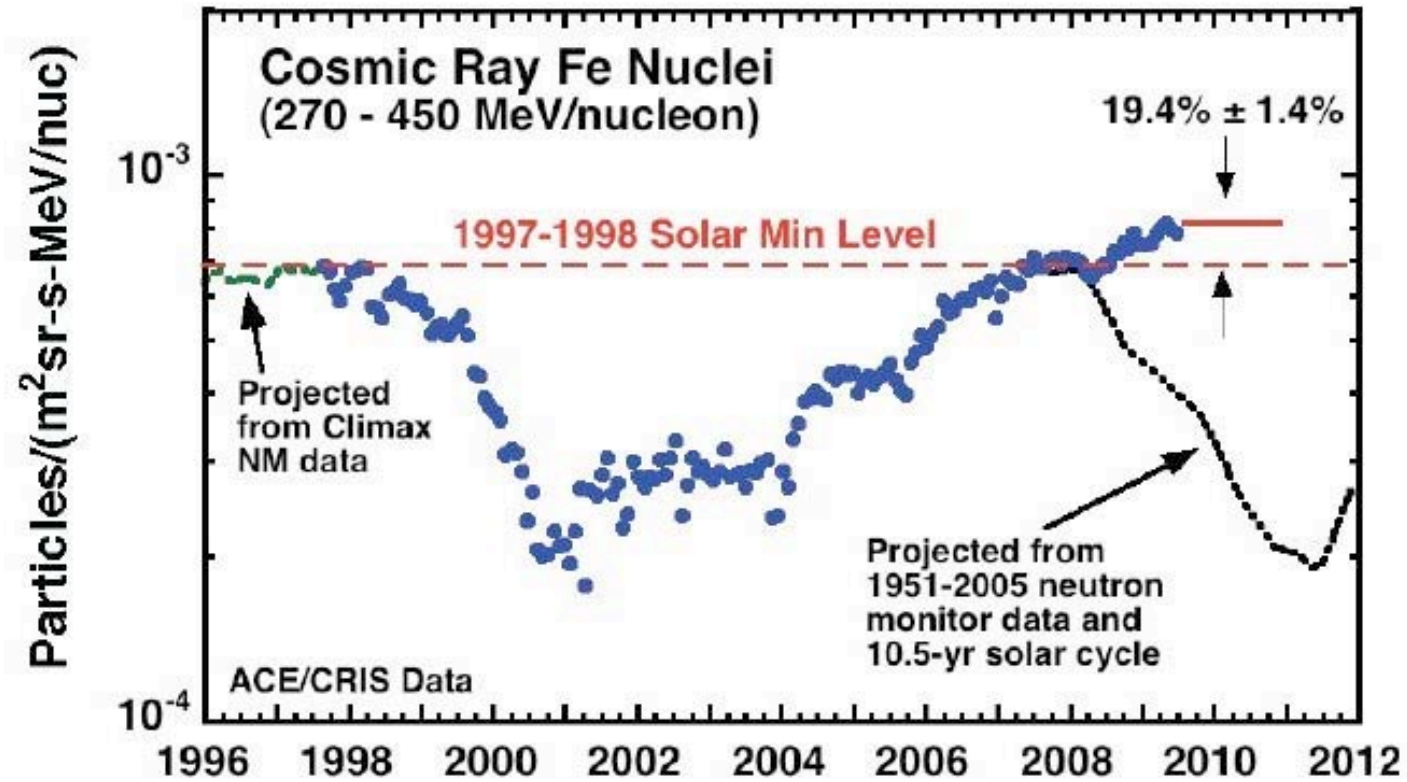


NOAA-NGDC sunspot and OMNI solar wind data (plot created by de Toma)

The story continues… 2009!

Cosmic rays at space-age high

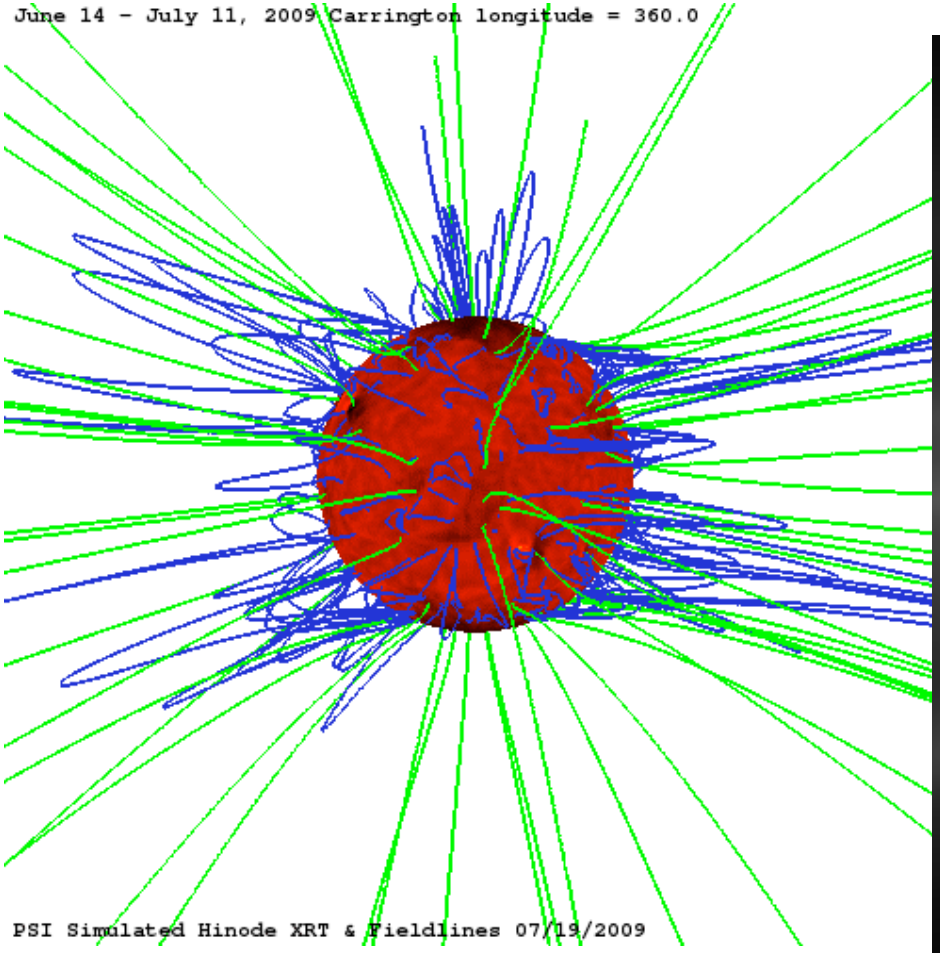
- Sensitive to continued decrease in solar wind magnetic field

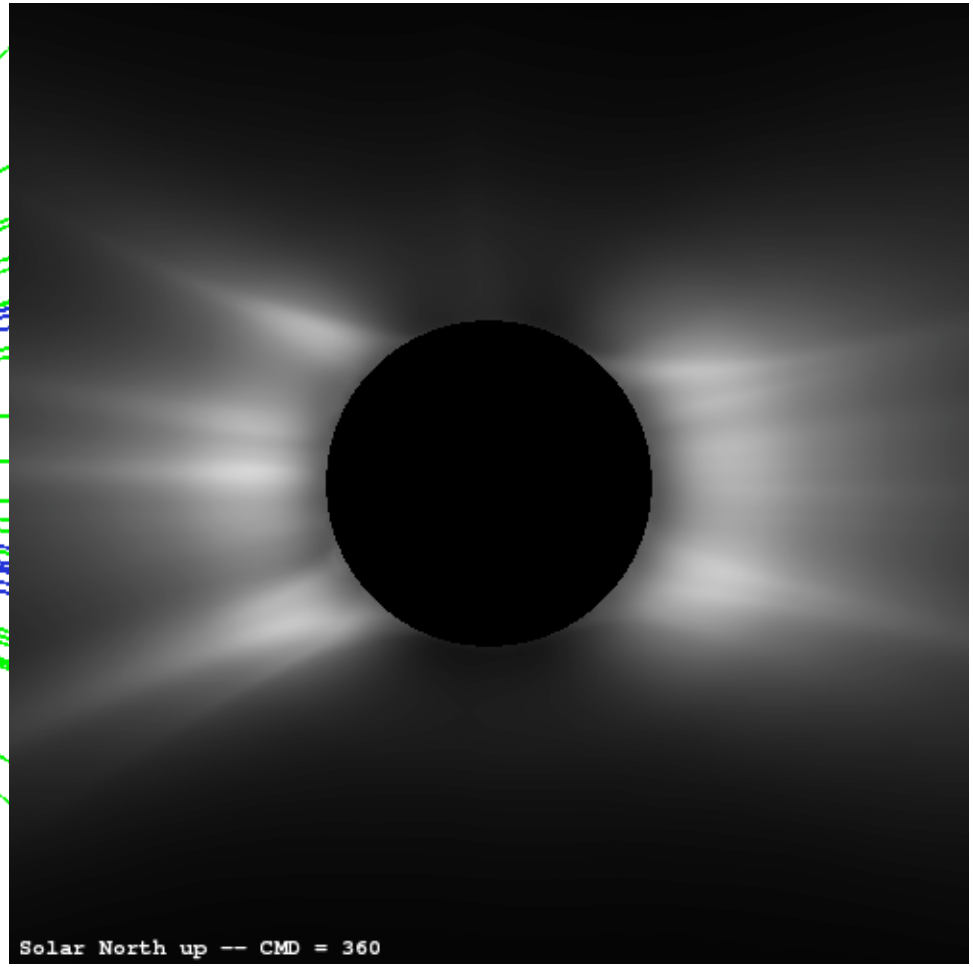


R. Mewaldt (Press release September 28, 2009)

“Porcupine Sun”: July 2009

And the distribution of open magnetic flux seems to be still evolving *(Predictive Science, Inc)*



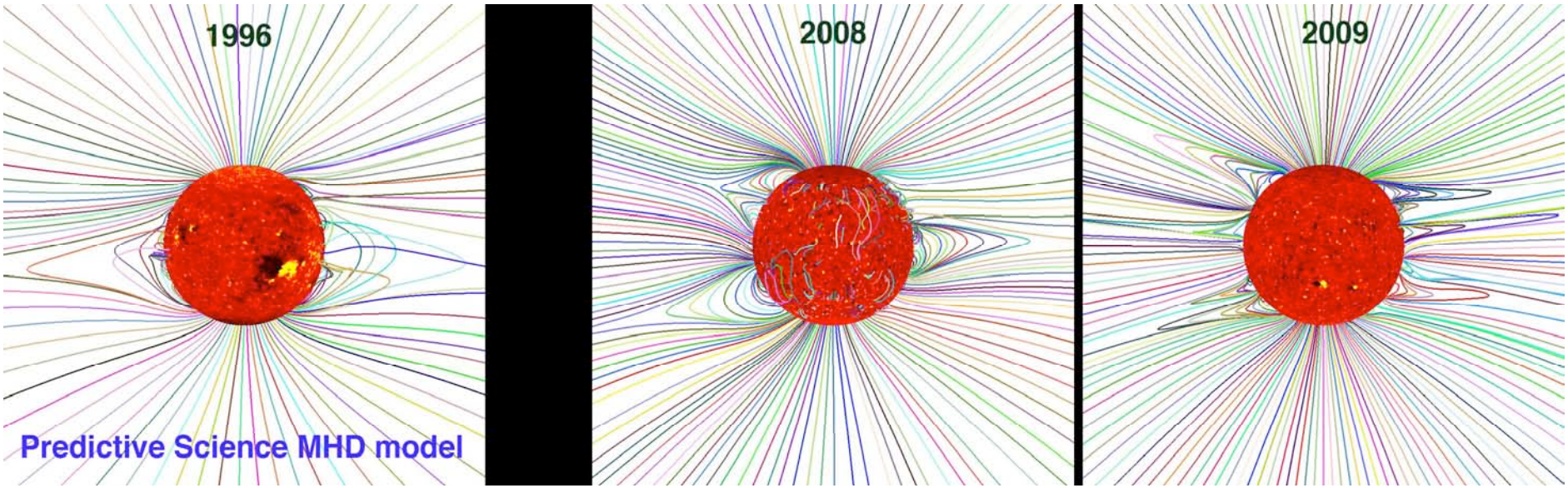


Distribution of open magnetic flux

The large, low-latitude regions of open magnetic flux of 2008 seems to have been replaced by smaller open field regions in 2009.

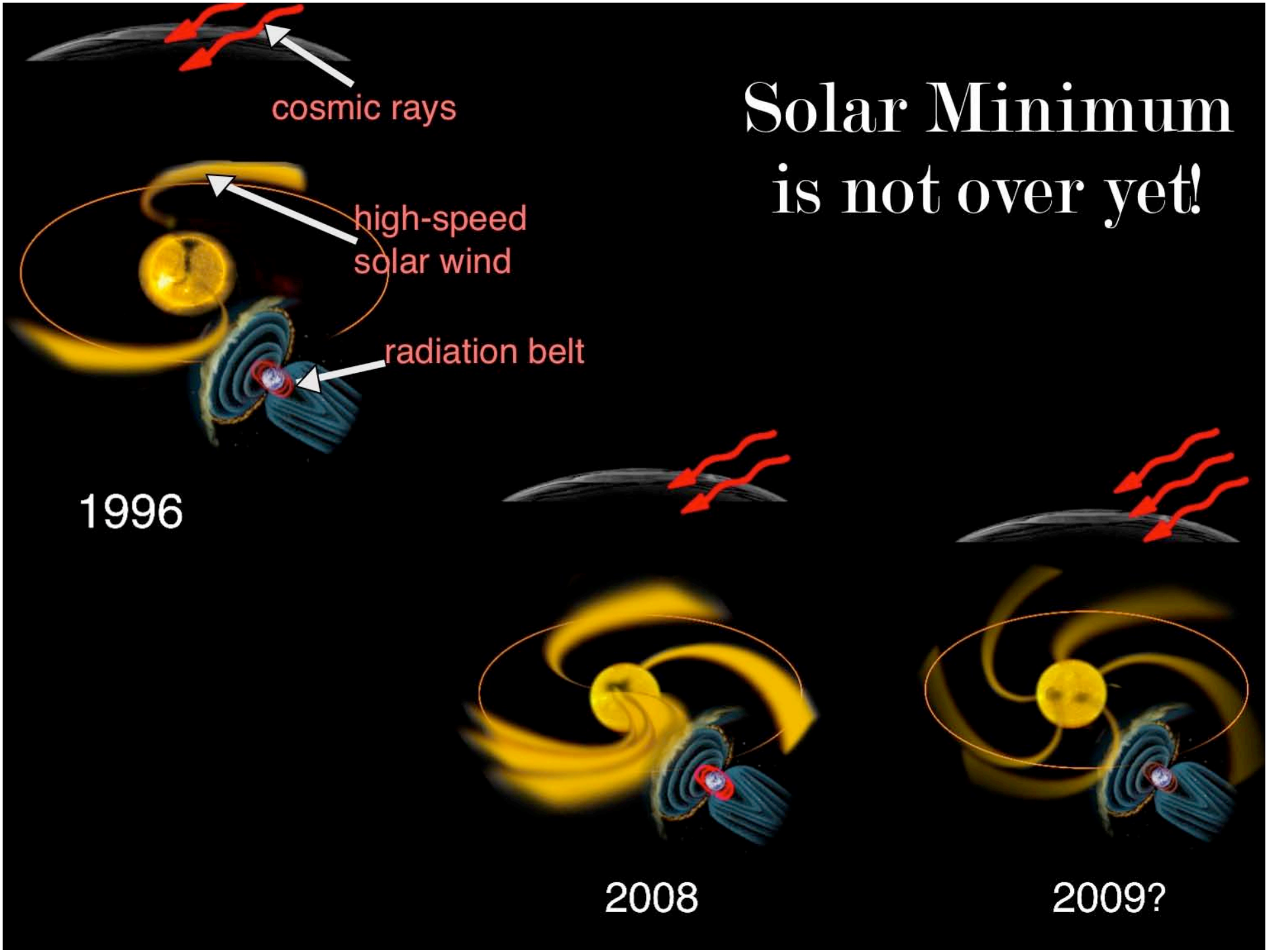
Has the fire hose has become a sprinkler-head?

Will the “classic” magnetic dipole (closed field at the equator) occur this minimum?



Summary

- The current solar minimum is not just deep, but also long and complex
- The complexity shapes the solar wind and impacts the Earth
  - For months after sunspots reached levels lower than last minimum, radiation in Earth's outer belt (geosynchronous-orbit) remained at high levels and, along with auroral and upper atmosphere parameters, rang with periodicities of solar wind.
- The length allows us to probe Sun-Earth physical processes
  - An approximately 2 year lag between the decrease in solar wind magnetic field and velocity provides an opportunity to pinpoint their relative roles in how solar wind drives the Earth.
- SSN does not provide information about how the solar magnetic open flux and related solar wind structures evolve
  - In late 2008/2009, after sunspots had been at very low levels for over a year, such evolution led to a decrease in fast wind intersecting the Earth, and the disappearance of the radiation belt. Models suggest that the open flux distribution may have shifted to weaker fields and smaller structures.



Solar Minimum is not over yet!