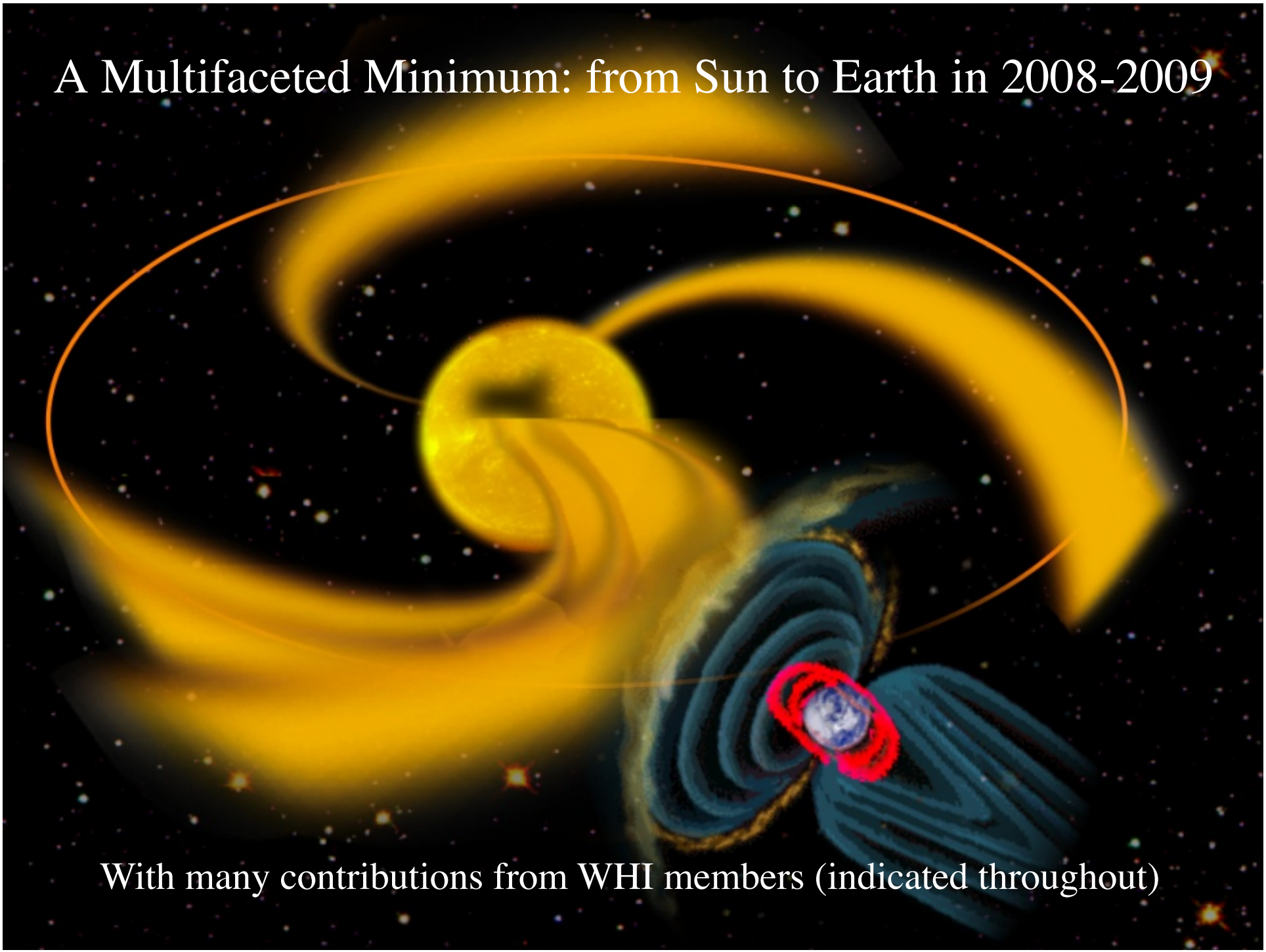
# A Multifaceted Minimum: from Sun to Earth in 2008-2009

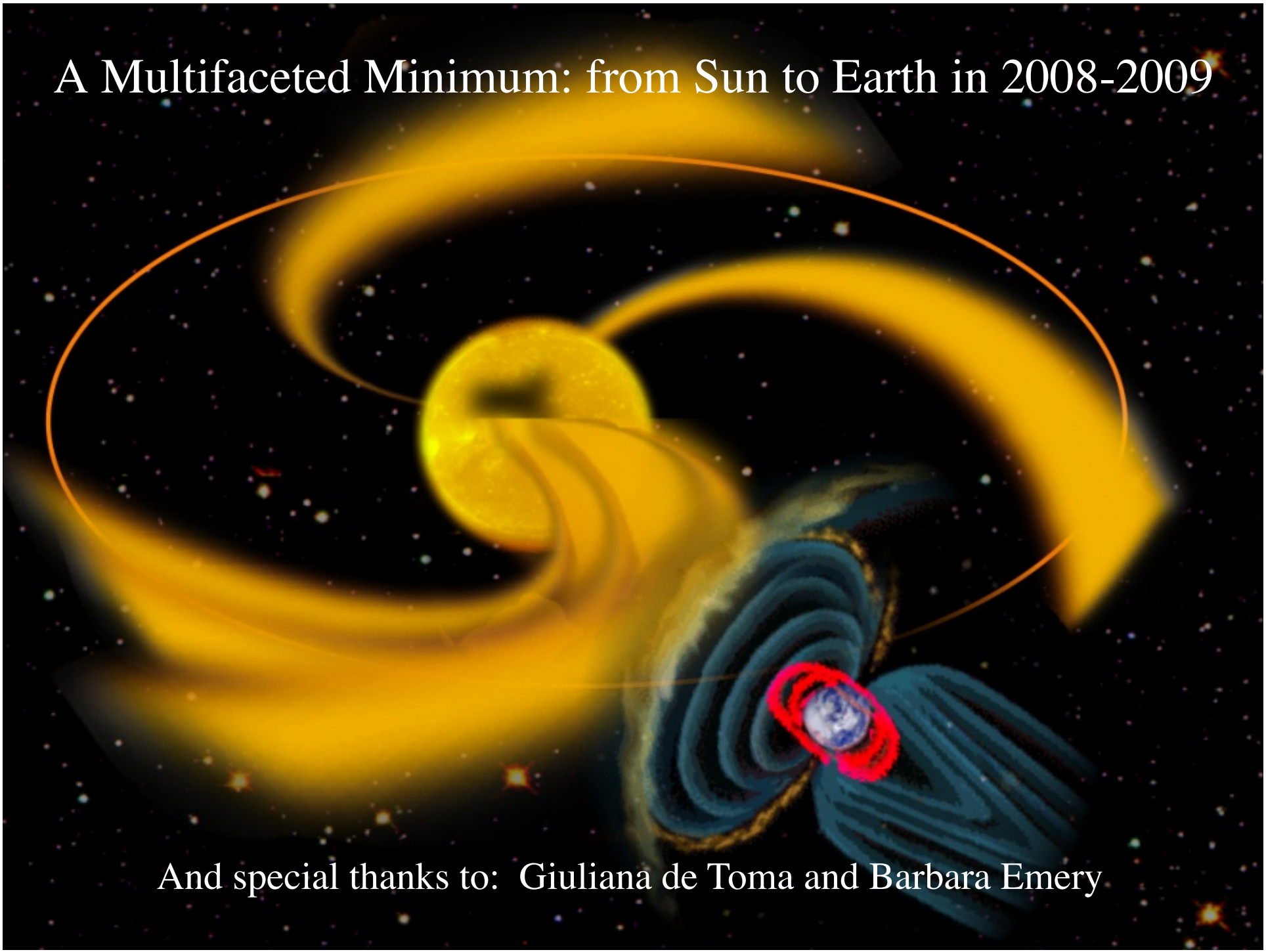
Sarah Gibson

# A Multifaceted Minimum: from Sun to Earth in 2008-2009



With many contributions from WHI members (indicated throughout)

# A Multifaceted Minimum: from Sun to Earth in 2008-2009



And special thanks to:  Giuliana de Toma and Barbara Emery


# Solar Minimum 2008-2009: Quiet, Complex, and Long

- 2008: A Deep Solar Minimum Begins…
  - *Whole Heliosphere Interval*
  - Sun Quiet but Complex
  - Heliosphere Still Ringing
- 2009: A Long Minimum Continues to Evolve..
  - Complexity Loses Coherence
  - Low-latitude Solar Open Flux Fades
  - Heliosphere Hits Bottom
- 2010: Activity Returns: Minimum is Over


# 2008

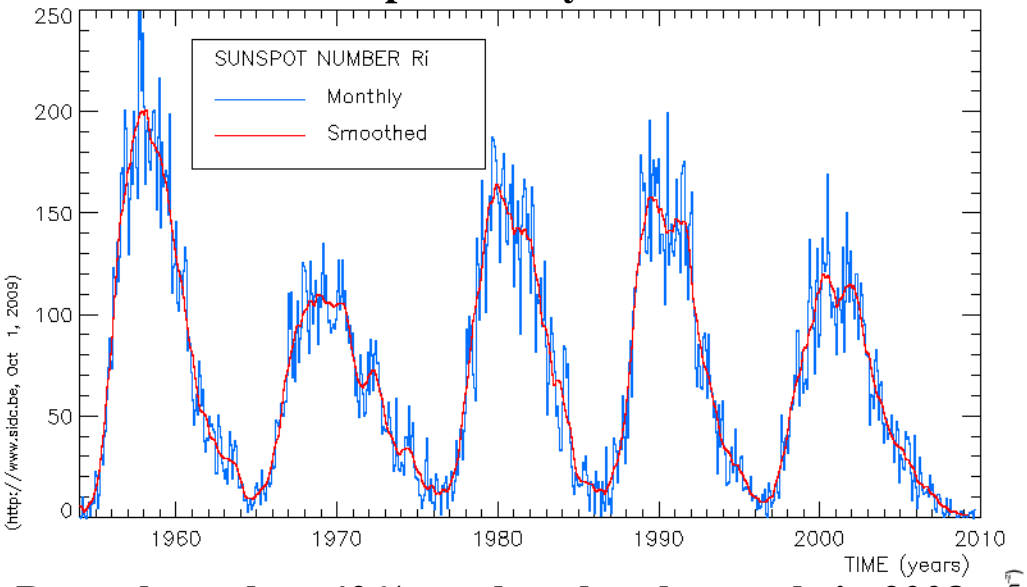
Science News Headlines:

- **"BLANKEST YEAR OF THE SPACE AGE"**
- **"SOLAR WIND LOSES POWER, HITS 50-YEAR LOW"**
- **"SPACE IS CLOSER THAN YOU THINK!"**

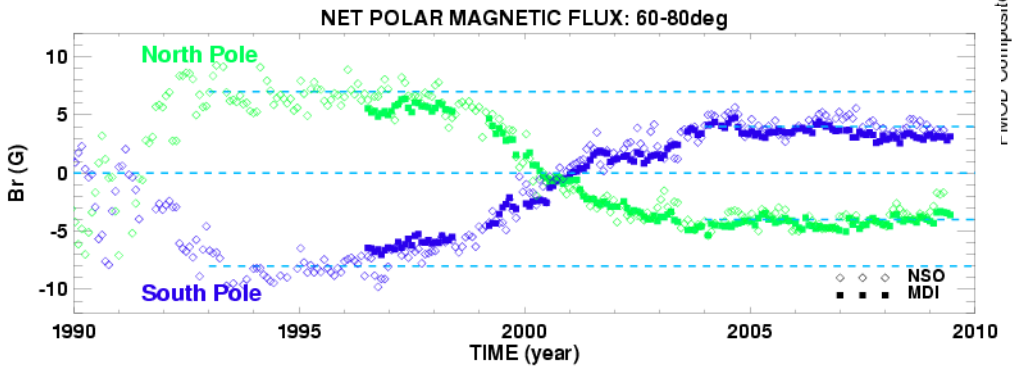
# Current solar minimum: unusually deep

## At the Sun…

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

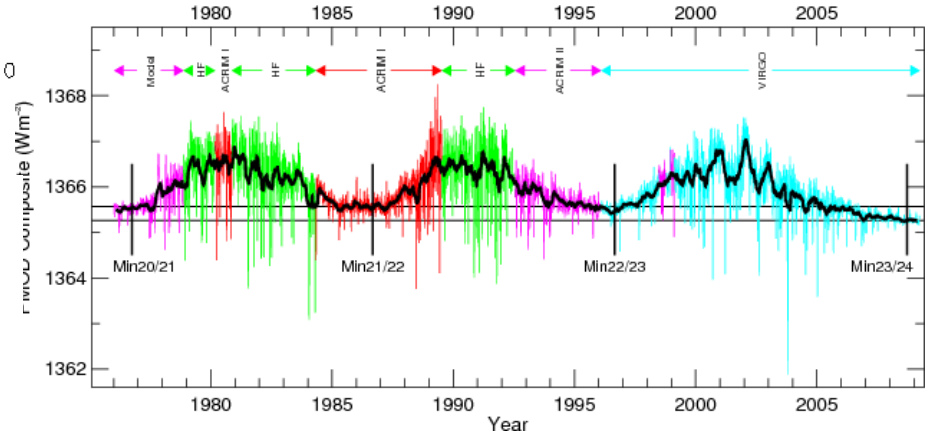



**B at solar poles ~40% weaker than last cycle in 2008**




MDI data: Courtesy Giuliana de Toma

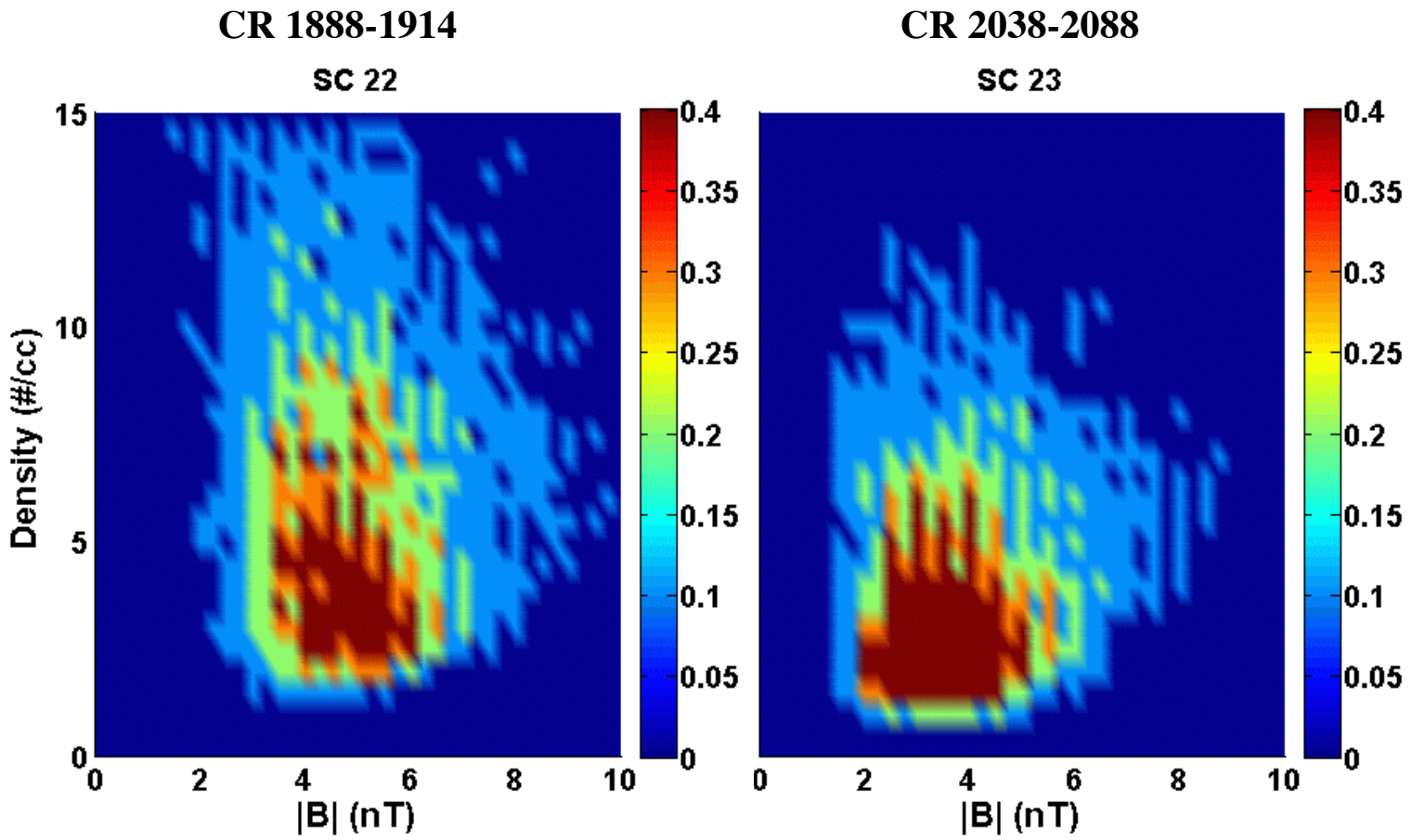
**Solar irradiance: may be depleted relative to past minima** (note difference is still small relative to min-max variation)




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

# Current solar minimum: unusually deep

## In the solar wind…



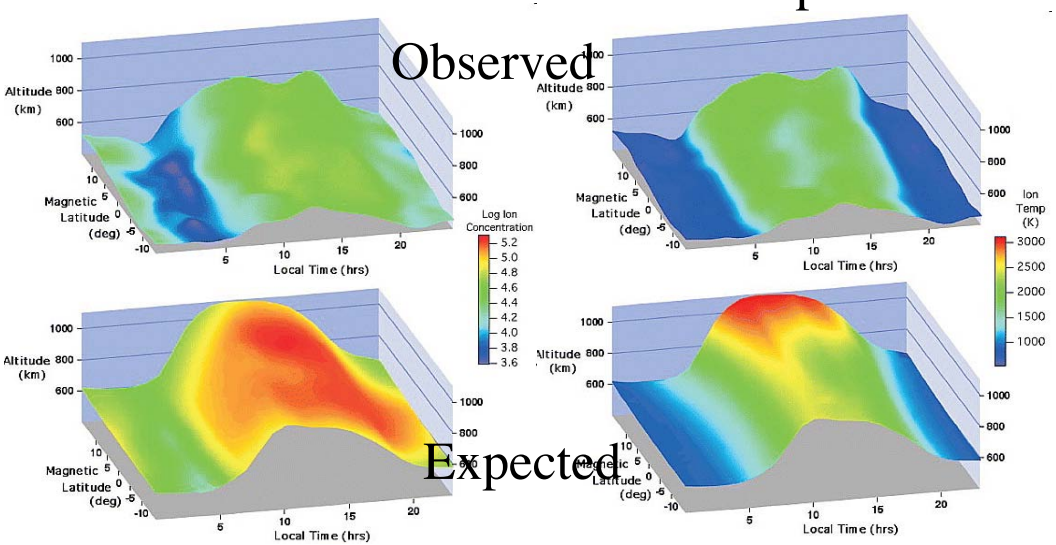

Courtesy C. Lee et al., 2009: "The Observed Weaker Magnetic Flux of the Solar Cycle 23 Mininum Period ", in preparation".

# Current solar minimum: unusually deep

## At the Earth.

Ion concentration

Ion temperature

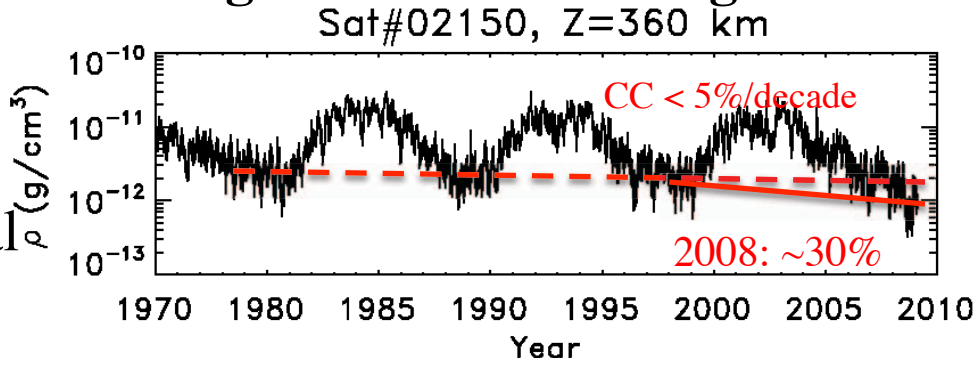



Earth's ionosphere thin and cool

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

Earth's thermospheric density is several times lower than can be accounted by climate change

**Long-term satellite-drag data**




Courtesy Stan Soloman, Tom Woods


# Whole Heliosphere Interval (WHI)

**Internationally coordinated observing and modeling effort**

Focus on observations originating from **Carrington Rotation 2068:** March 20 - April 16, 2008

- **Synoptic observing programs**: Broad heliospheric coverage, provide context and baseline measurements
- **Targeted observing campaigns:** Coordinated observations run during CROT 2068
- Observational input from **27 solar, 19 heliospheric, and 21 geospace instruments**
- **~200 people** "officially registered"

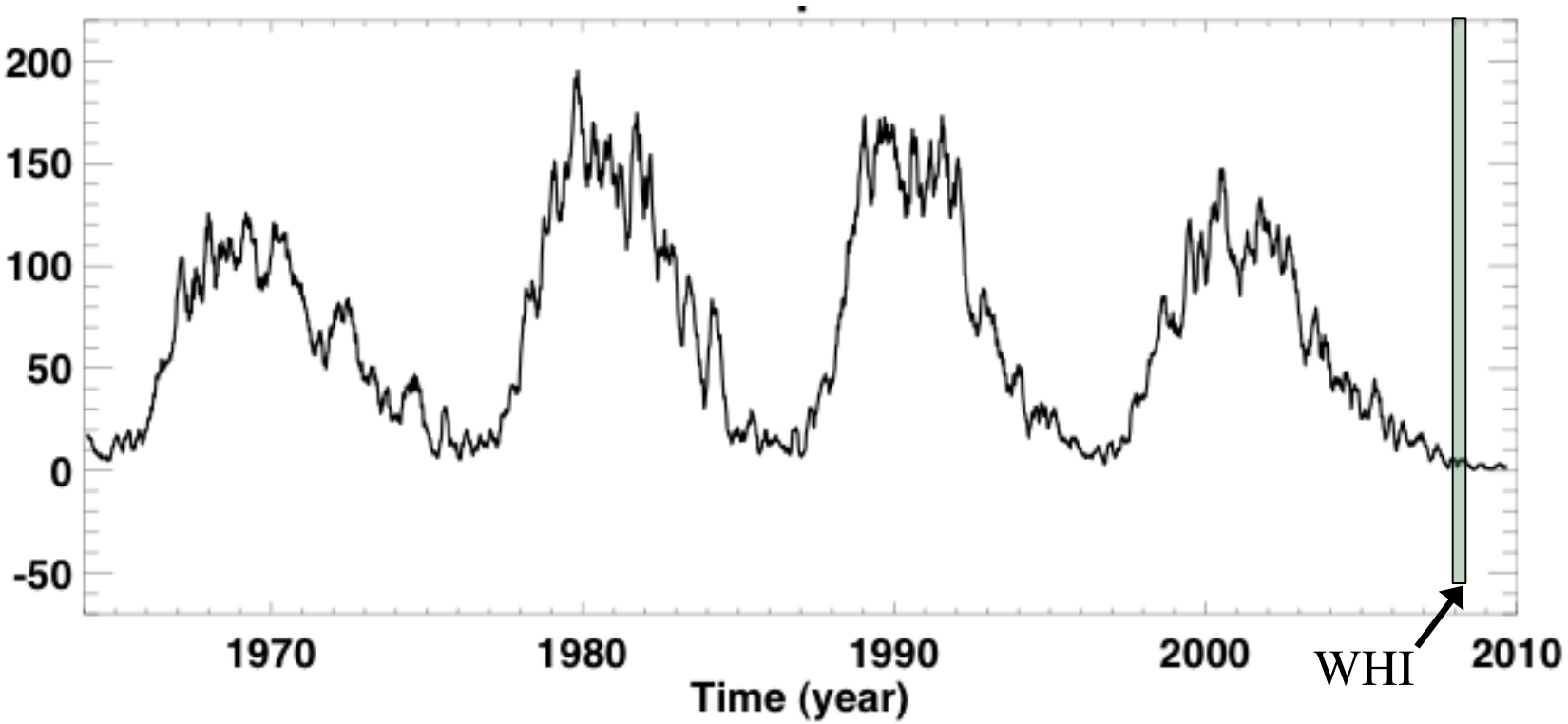
**Science goals**

1. **Connect the origins and effects of solar structure and activity through the solar wind to the Earth and other planetary systems**
2. **Characterize the 3-D solar minimum heliosphere**

# Where WHI fits in to minimum….

Typical of the **early stage** of the recent minimum.

- WHI had minimum-level sunspot number

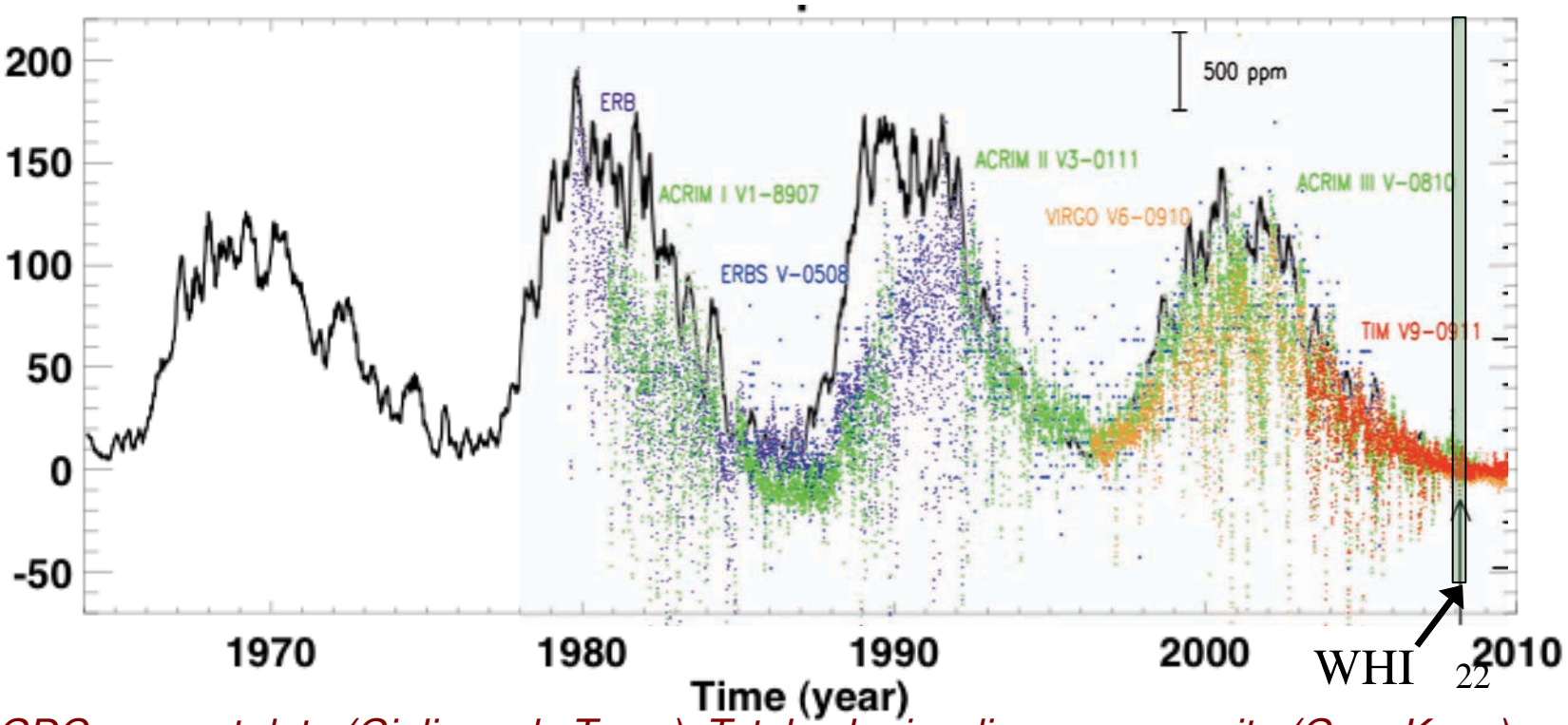



*NOAA-NGDC sunspot data (plot created by de Toma)*

# Where WHI fits in to minimum….

Typical of the **early stage** of the recent minimum.

- WHI had minimum-level irradiance




*NOAA-NGDC sunspot data (Giuliana de Toma); Total solar irradiance composite (Greg Kopp)*

# Where WHI fits in to minimum….

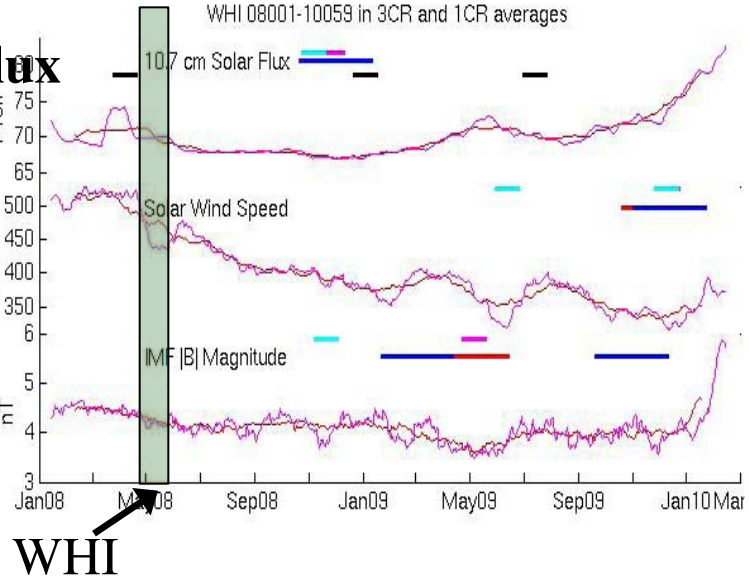
Typical of the **early stage** of the recent minimum.

- WHI **solar wind speed, radiation belt population**, and **auroral/ geomagnetic activity still high** at the Earth during WHI compared to eventual minima (late in 2009)

**Solar flux (10.7)**

**$V_{sw}$**

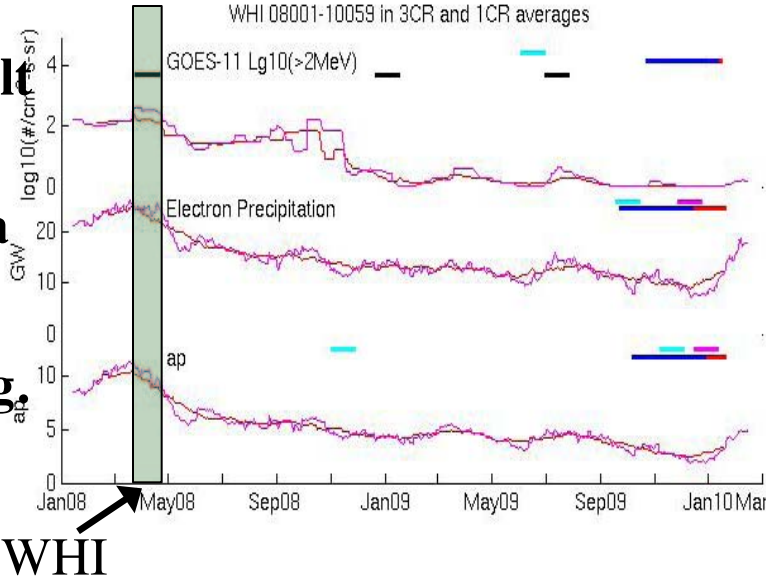
**$|B|_{sw}$**




**Rad. belt**

**Aurora**

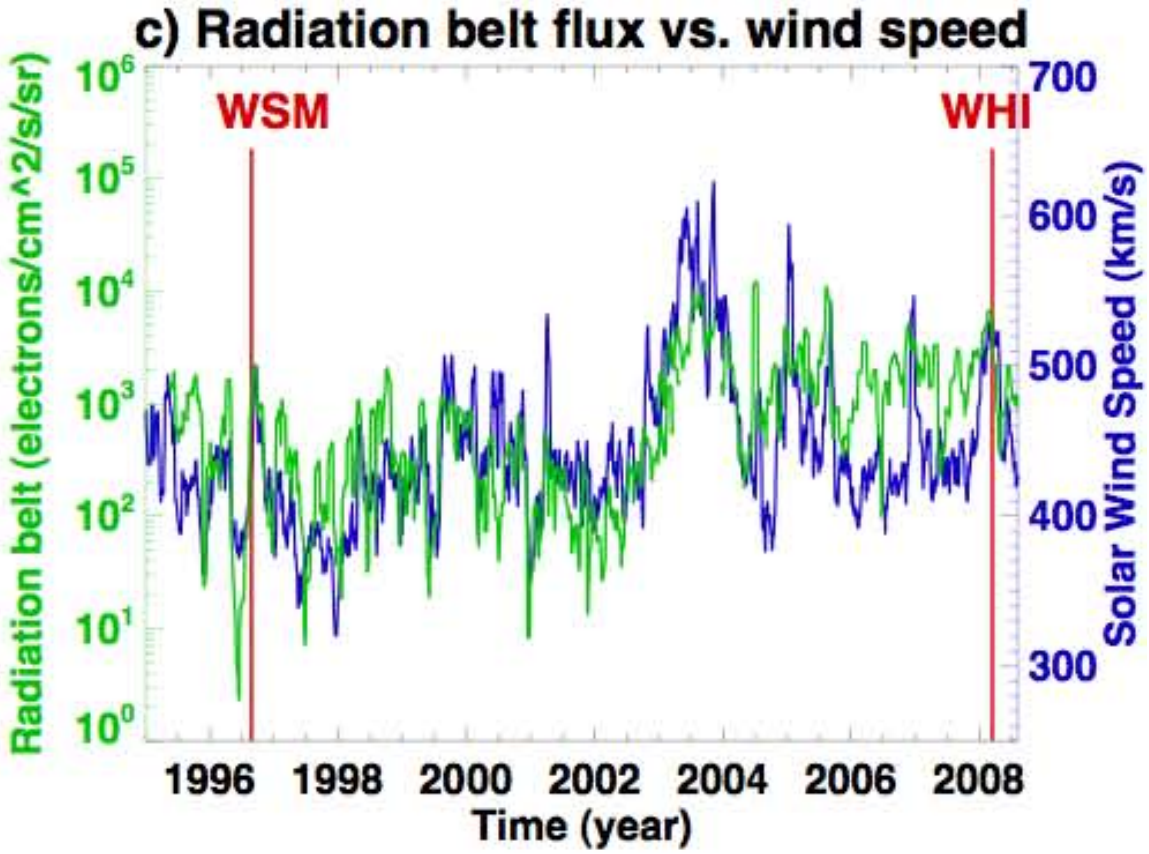
**Geomag, (ap)**




Courtesy Barbara Emery

# Where WHI fits in to minima in general!

- Wind speed and radiation belt flux **high compared to prior minimum**, too!




Solar wind speed at Earth
- **13% increase**

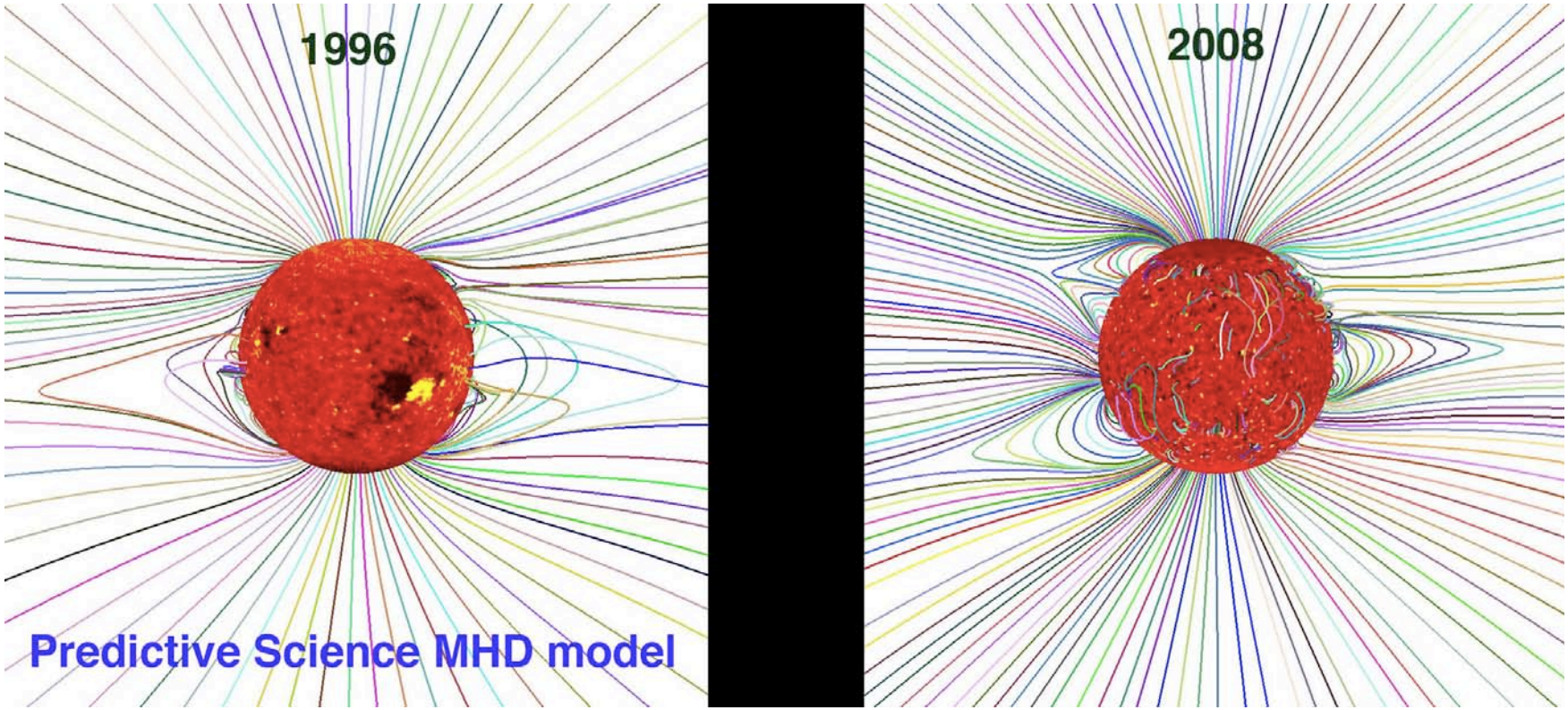
Radiation belt flux
- **340 % increase (71% log)**

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


# Current solar minimum: unusually complex

## At the Sun...

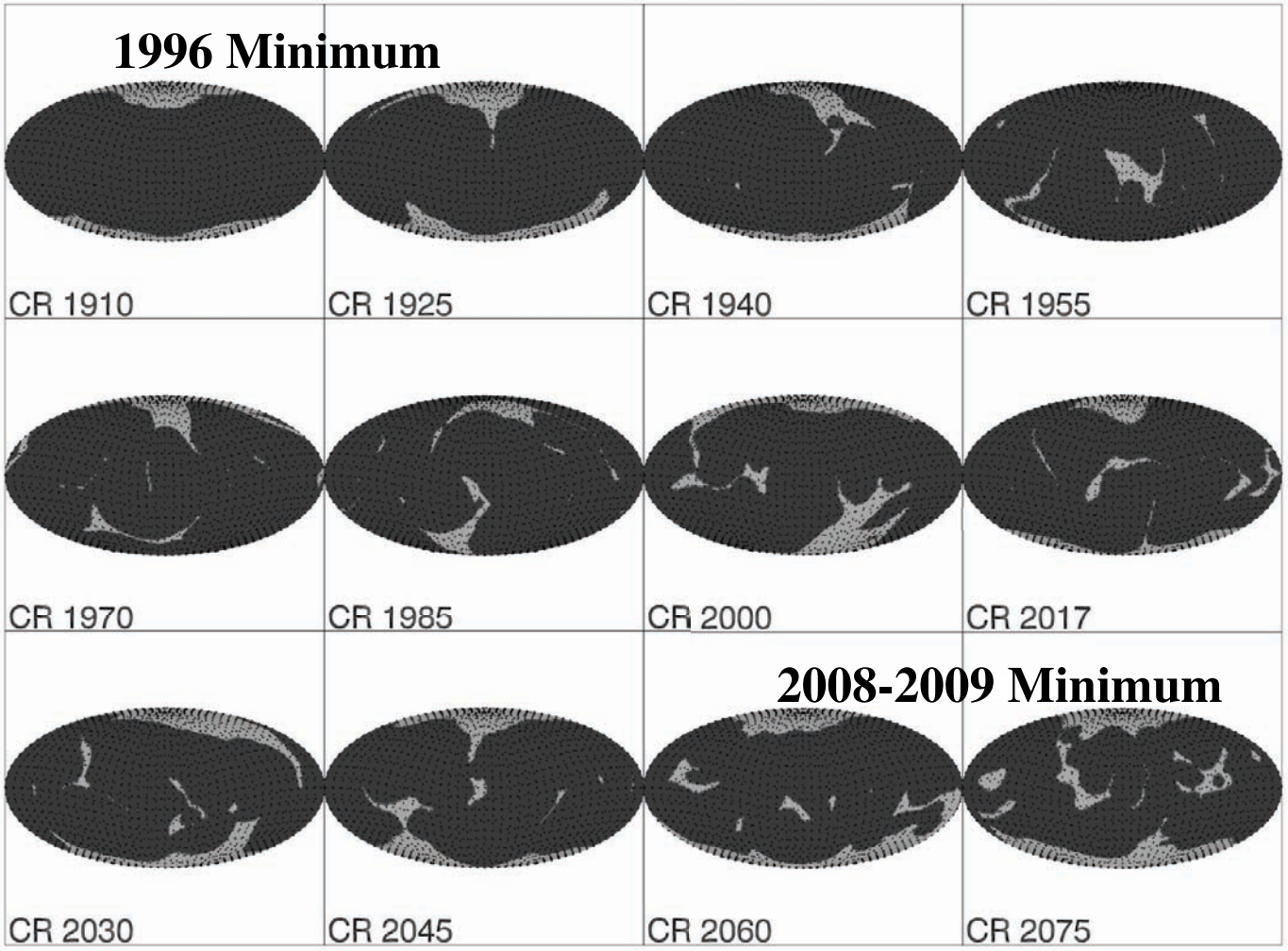
More open magnetic flux at low latitudes in 2008 than in 1996; less dipolar.



# Current solar minimum: unusually complex

## At the Sun...

More **low-latitude open flux – coronal holes**



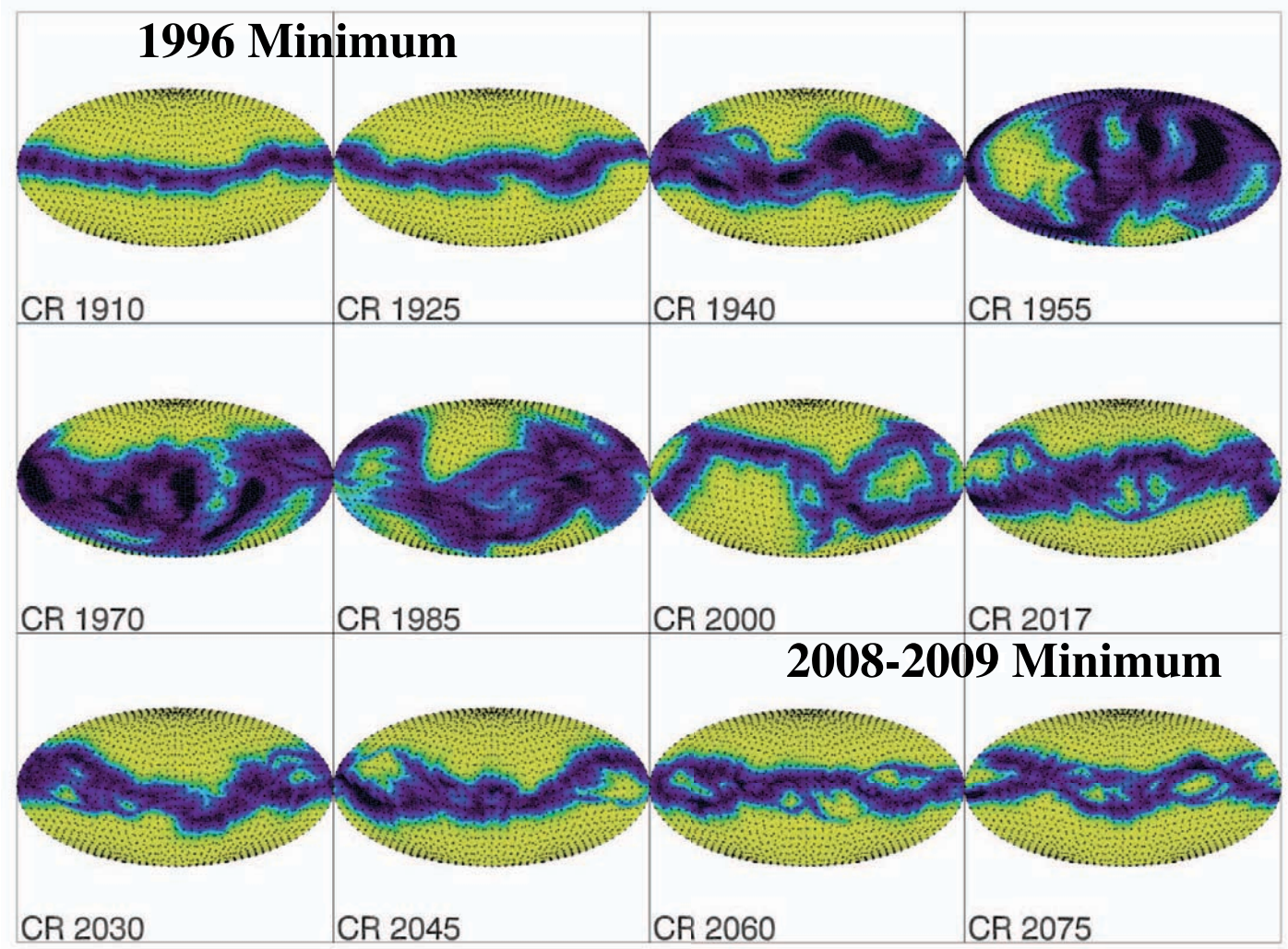

MAS coronal MHD model, open field line footpoint area

Courtesy Pete Riley

# Current solar minimum: unusually complex

## In the solar wind…

**Warped heliospheric current sheet (HCS) and fast wind streams at low latitudes**




MAS coronal MHD model, solar wind speed at 30 Rsun

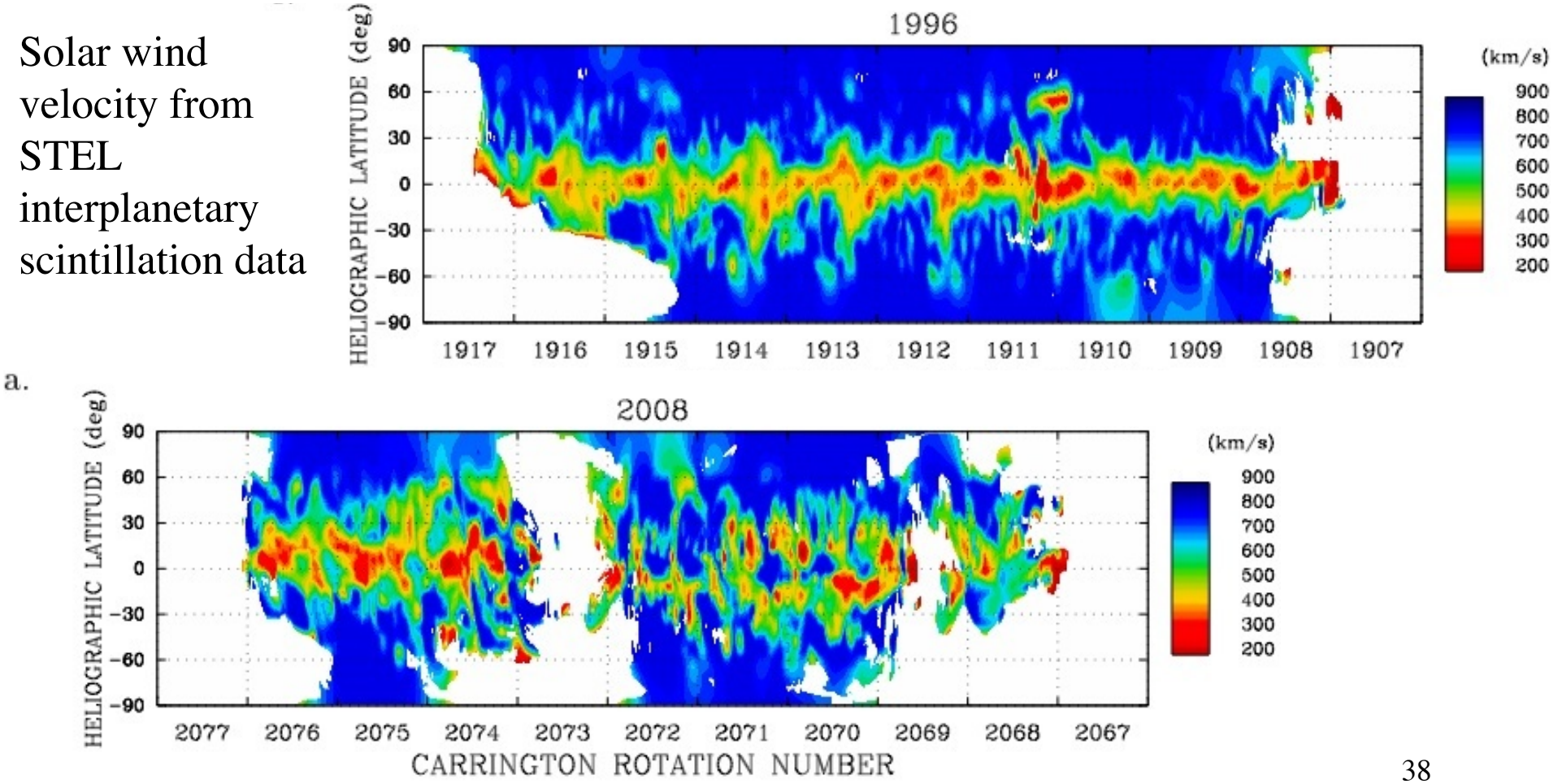
Courtesy Pete Riley

# Current solar minimum: unusually complex

## In the solar wind…

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

Solar wind velocity from STEL interplanetary scintillation data






Tokumaru et al, GRL, 36, 9, 2009

# Current solar minimum: unusually complex

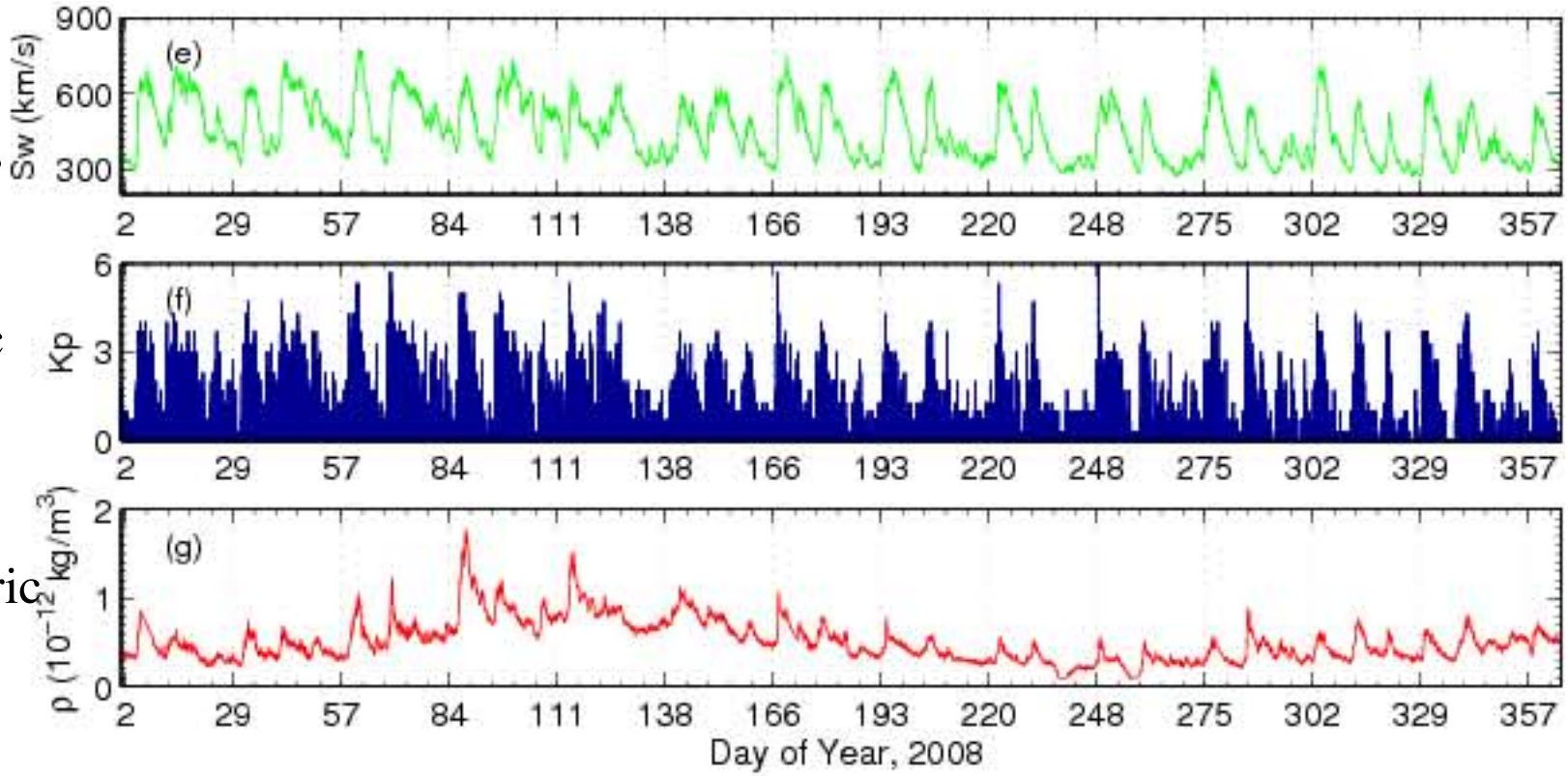
## At the Earth...

Geospace was periodically driven **throughout 2008**

High-speed wind streams

Geomagnetic index Kp

Thermospheric density




Courtesy Jiuhou Lei

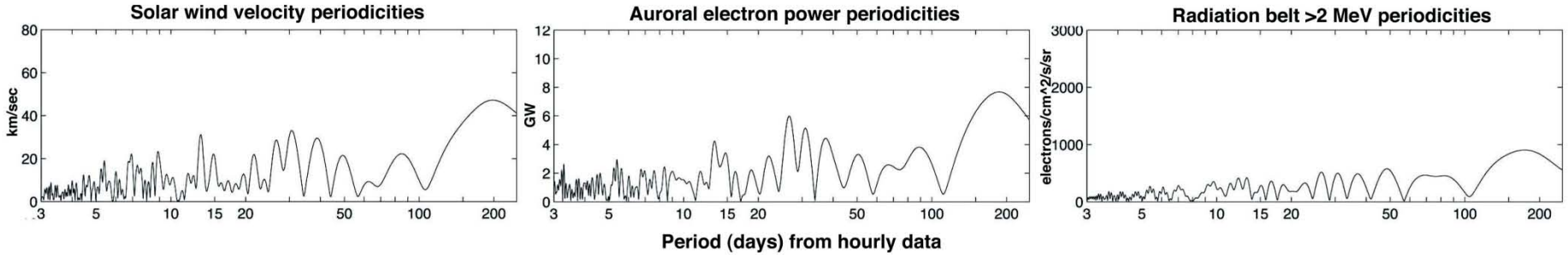
# Current solar minimum: unusually complex

## At the Earth.

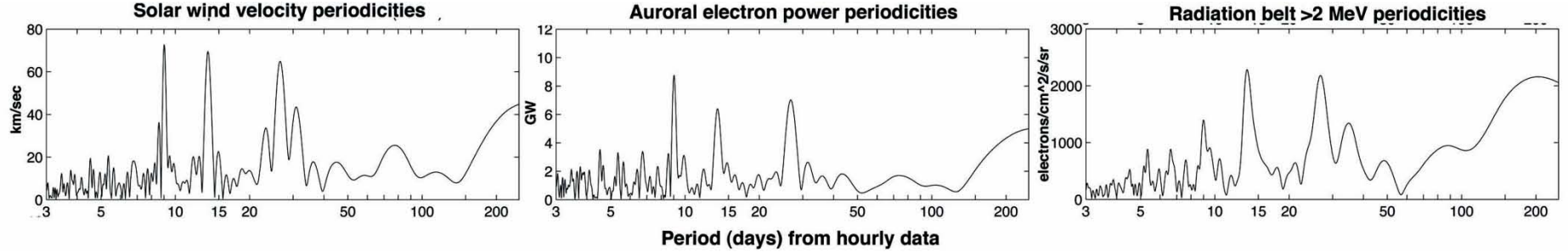
Periodicities (9, 13, 27 day) of wind → periodicities in aurora and radiation belt

**The Earth was ringing for most of 2008**

**WSM** (1996)




**WHI** (2008)



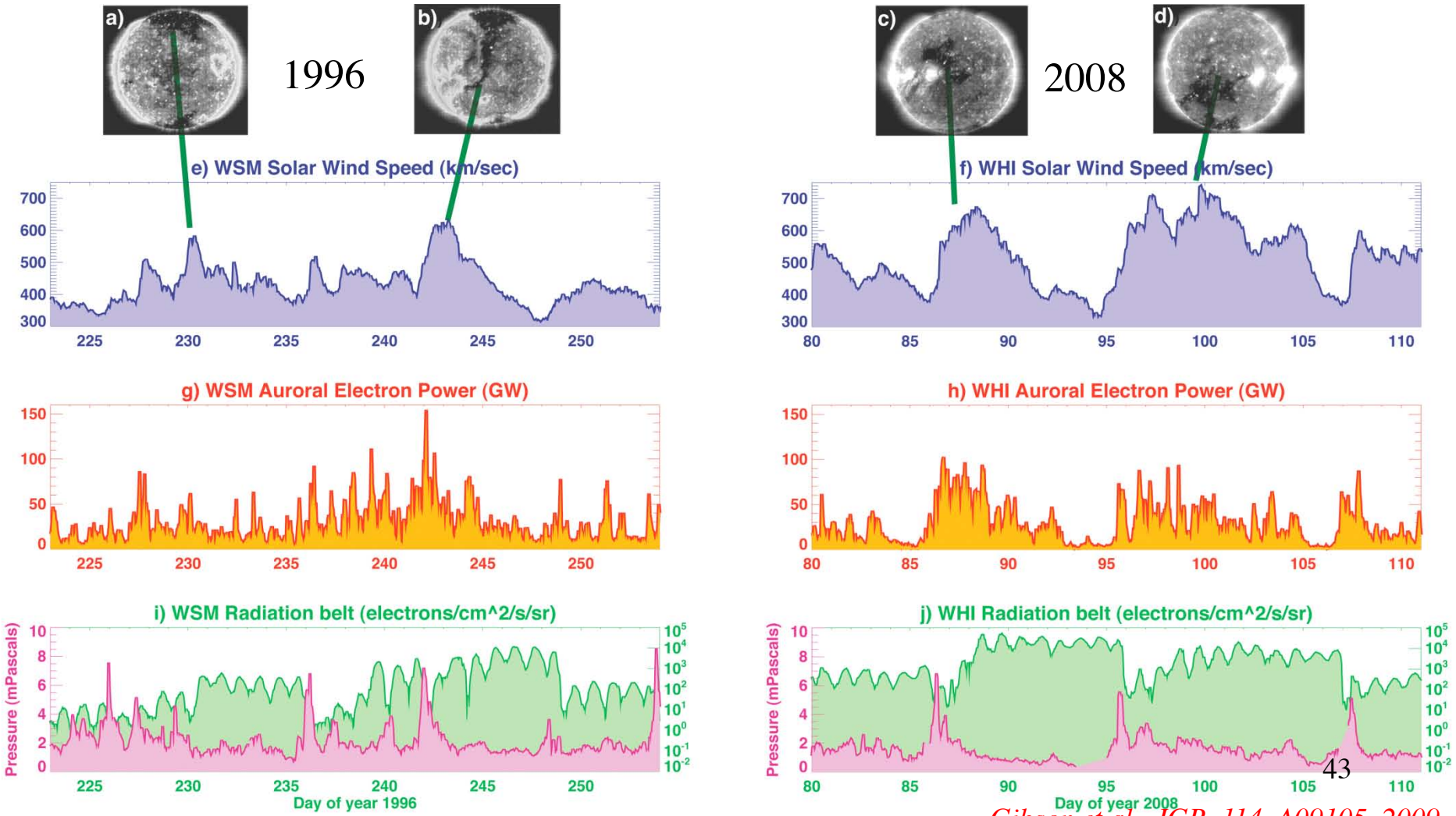

Periodicities determined for 9-months around WSM and WHI



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

# End to end during WHI: analysis

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

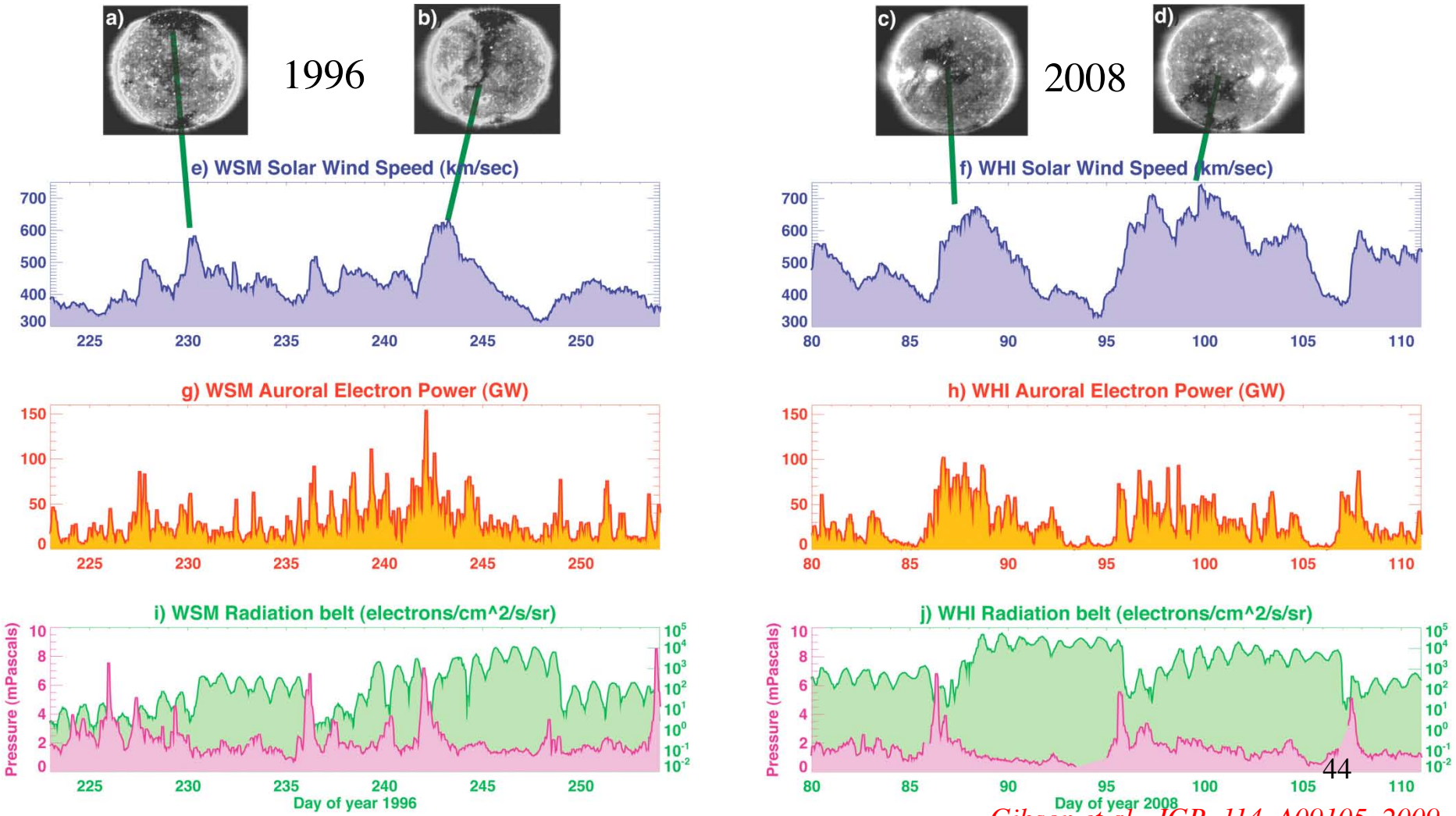





*Gibson et al., JGR, 114, A09105, 2009*

# End to end during WHI: analysis

Auroral power correlates to B*V

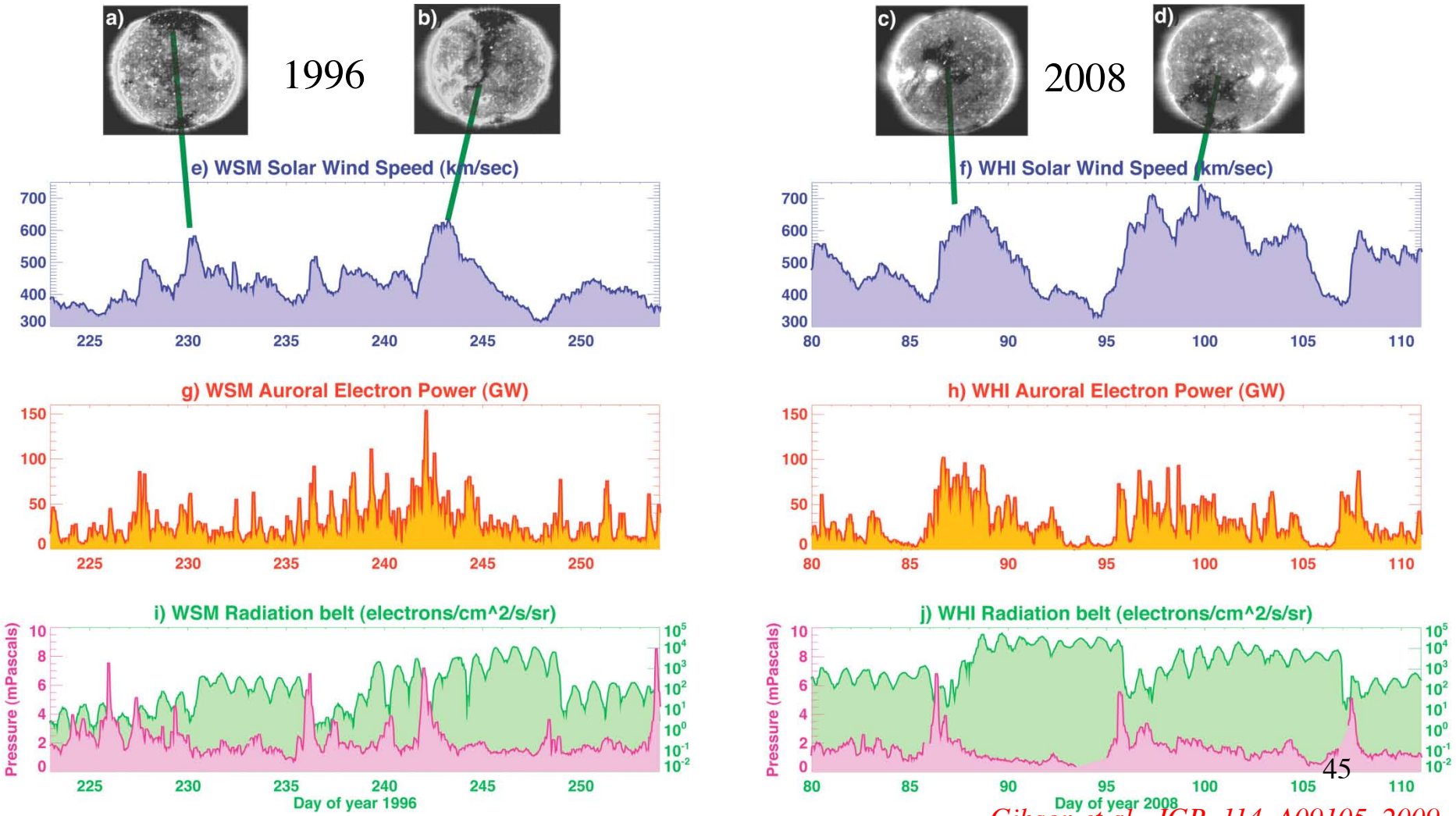





*Gibson et al., JGR, 114, A09105, 2009*

# End to end during WHI: analysis

WHI: clearly modulated (but weak) aurora

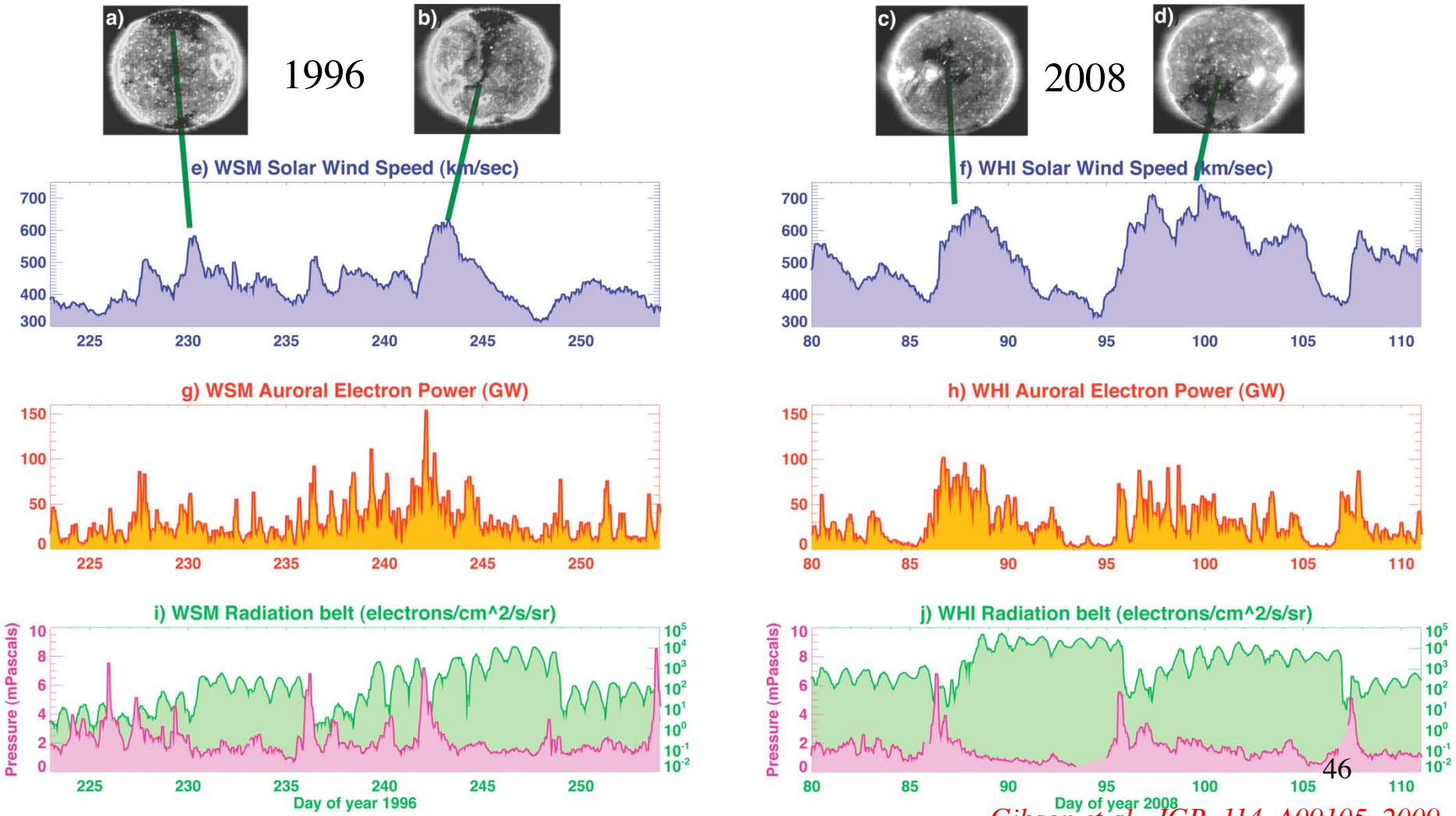





*Gibson et al., JGR, 114, A09105, 2009*

# End to end during WHI: analysis

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

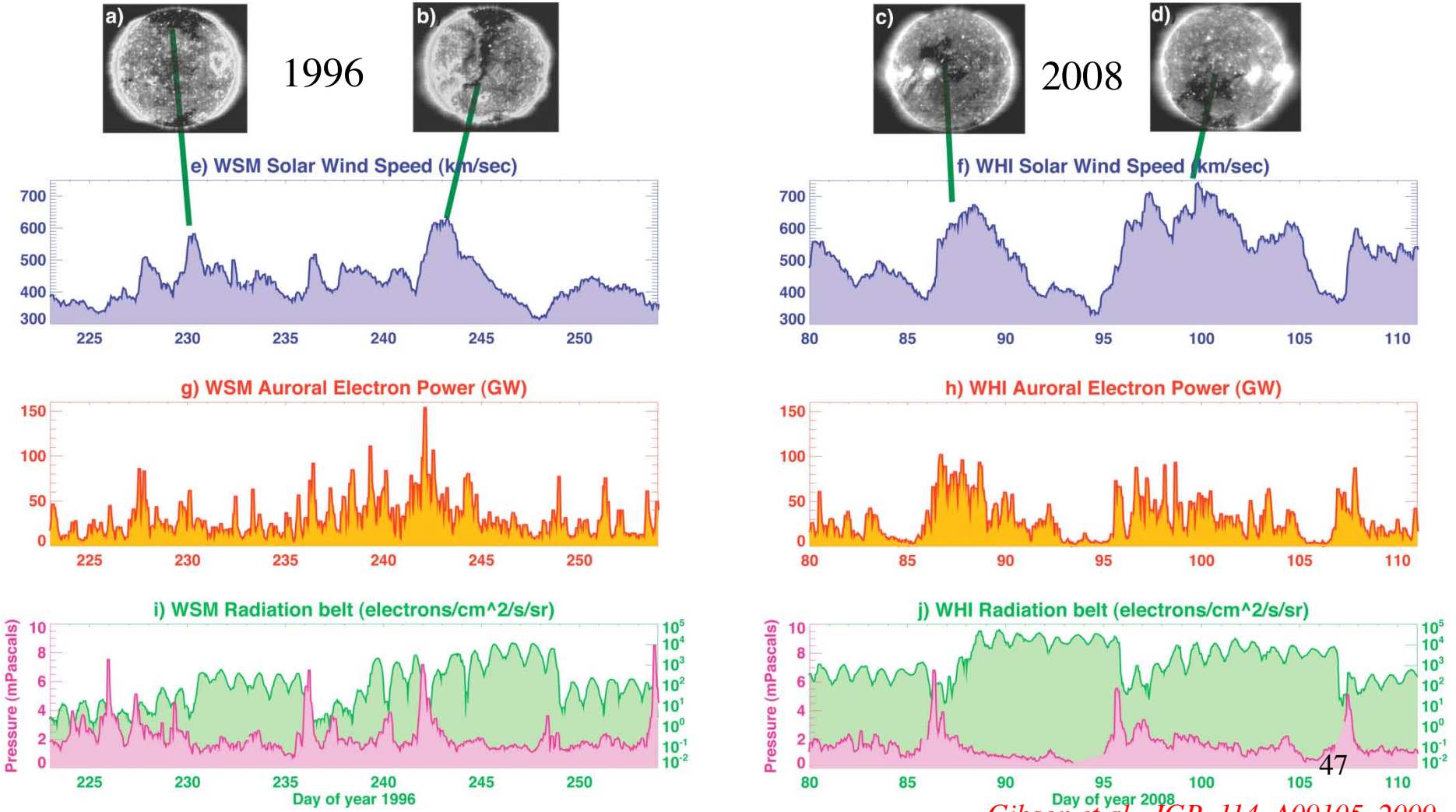





*Gibson et al., JGR, 114, A09105, 2009*

# End to end during WHI: analysis

WHI: clearly modulated and enhanced radiation belt






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


# 2009

Science News Headlines:

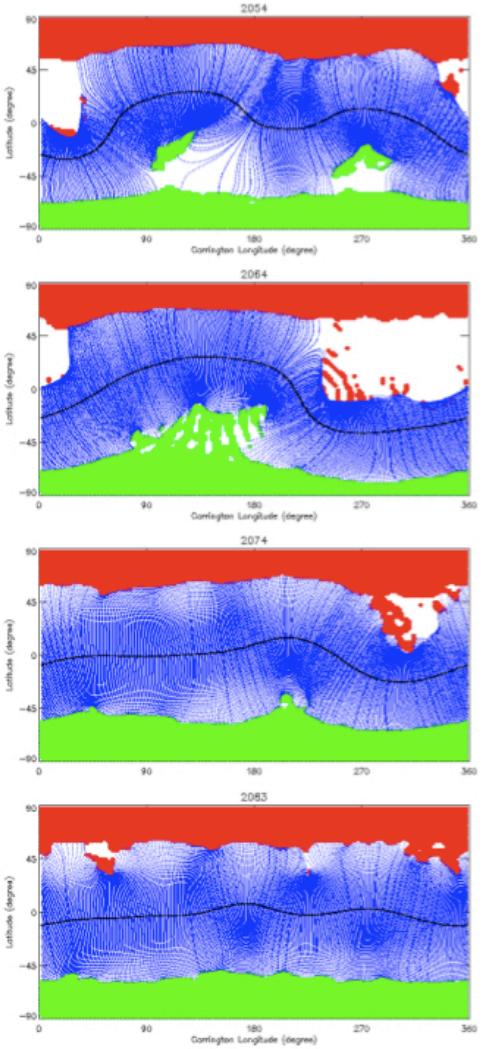
- **"DEEP SOLAR MINIMUM"**
- **"ARE SUNSPOTS DISAPPEARING?"**
- **"COSMIC RAYS HIT SPACE-AGE HIGH"**

# Current solar minimum: evolution

## At the Sun…

*GONG synoptic polarity maps from CR 2054 – 2083.*

Towards the end of 2008, **large low-latitude coronal holes disappeared,** and **HCS flattened**



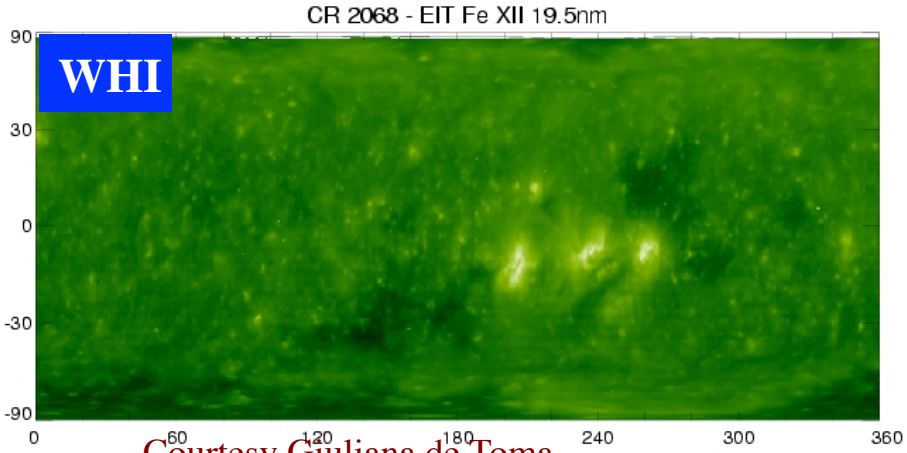

2054
Feb. 07

2064
Dec. 07

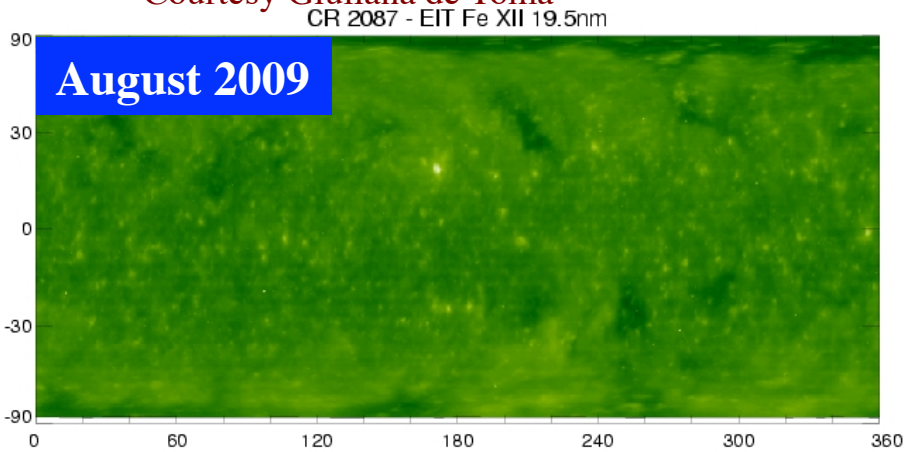
**WHI**

2074
Sep. 08

2083
May 09




Courtesy Giuliana de Toma

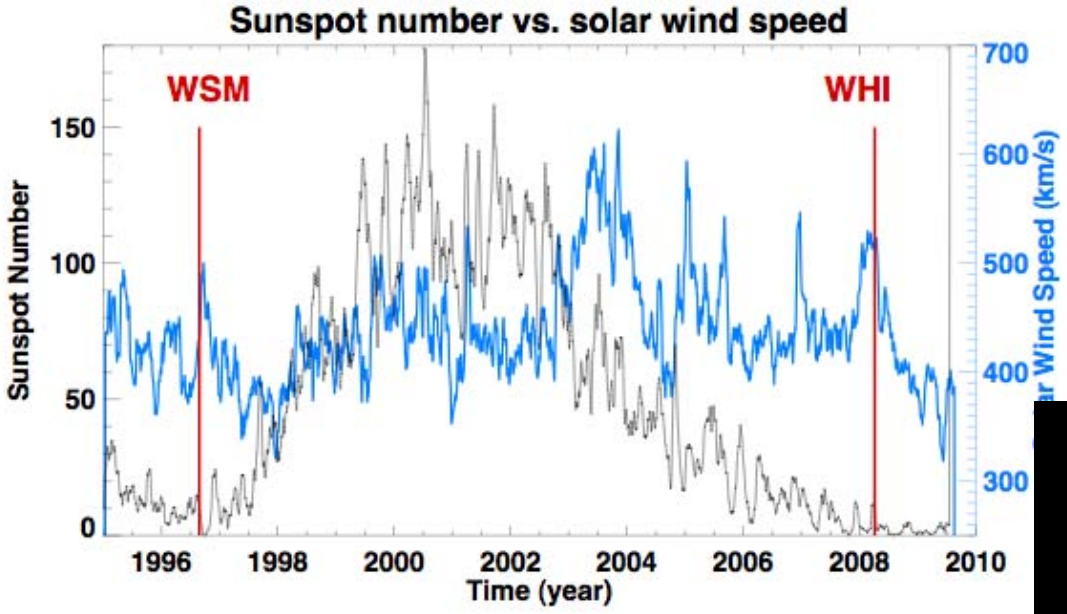


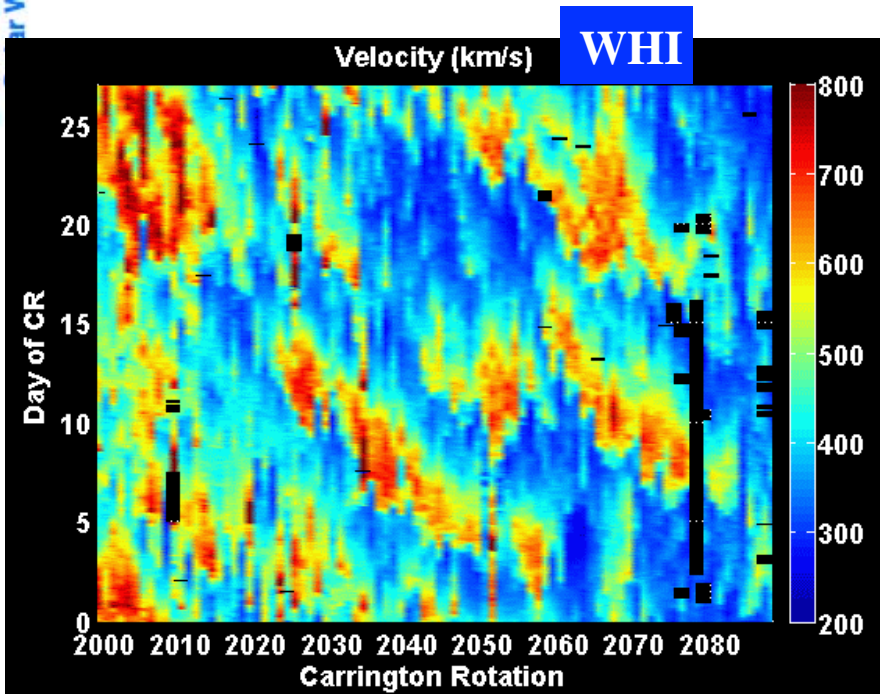

Note some small mid-latitude coronal holes are present: More on that in a moment.

# Current solar minimum: evolution

## In the wind…

As low-latitude coronal holes diminished, **high-speed streams tapered off**

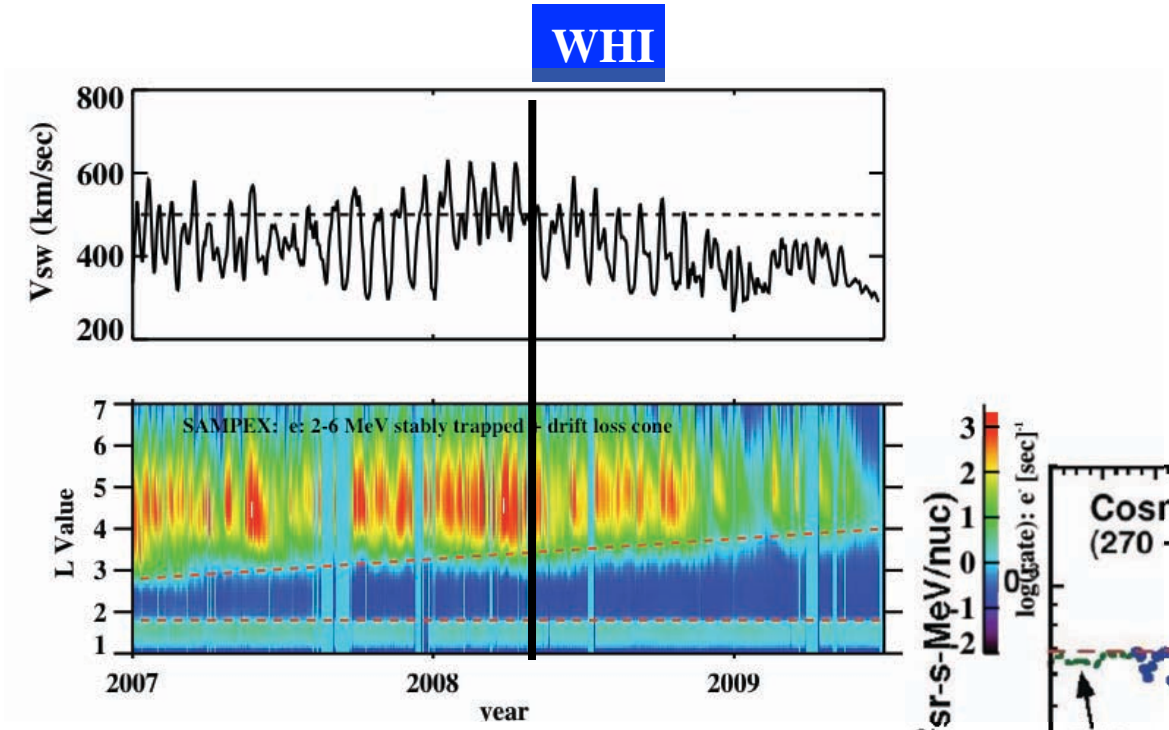



*Courtesy C. Lee et al., 2009: "Organization of Energetic Particles by the Solar Minimum Phase of Solar Cycle 23", in preparation".*

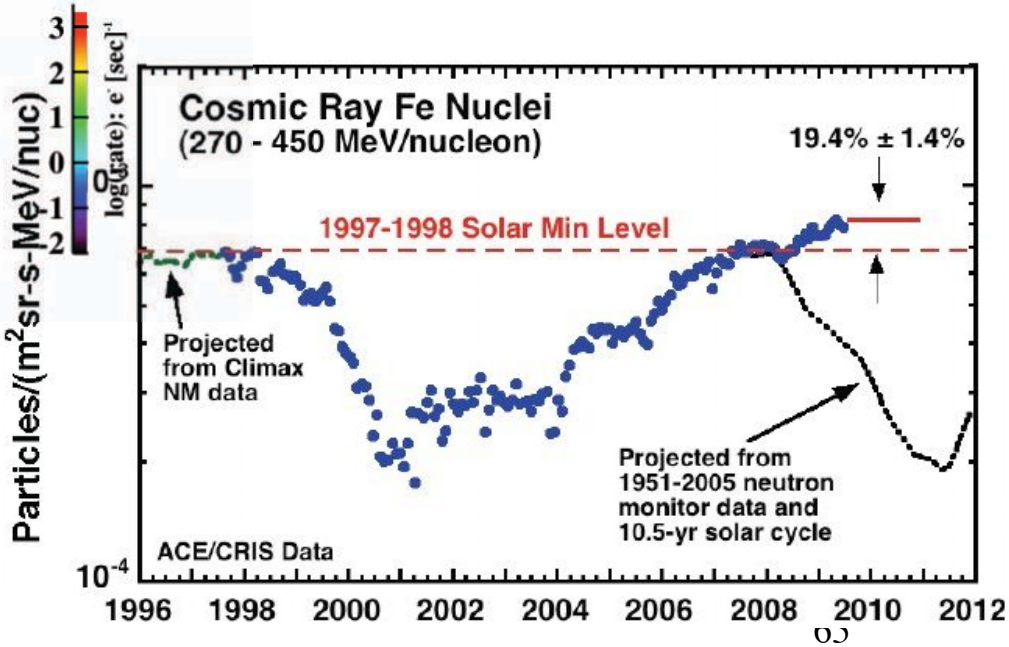
# Current solar minimum: evolution

As the high-speed streams disappeared, **radiation belts fell to record lows**, and **cosmic rays reached record highs**




*Courtesy Dan Baker*

## At the Earth.

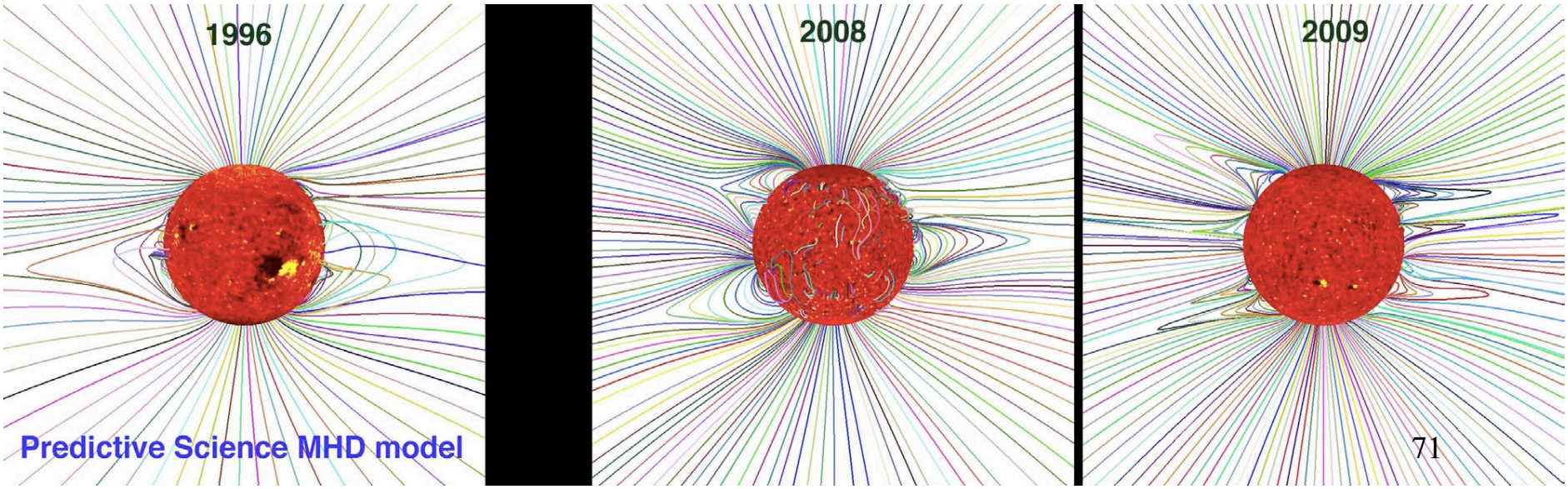



*Courtesy Dick Mewaldt*


# Current solar minimum: evolution

However, the disappearance of large, low-latitude coronal holes in 2009 did not mean that the global field became completely dominated by the dipole as in 1996.

On the contrary, the MAS model shown below exhibited small open field regions at all latitudes in 2009.

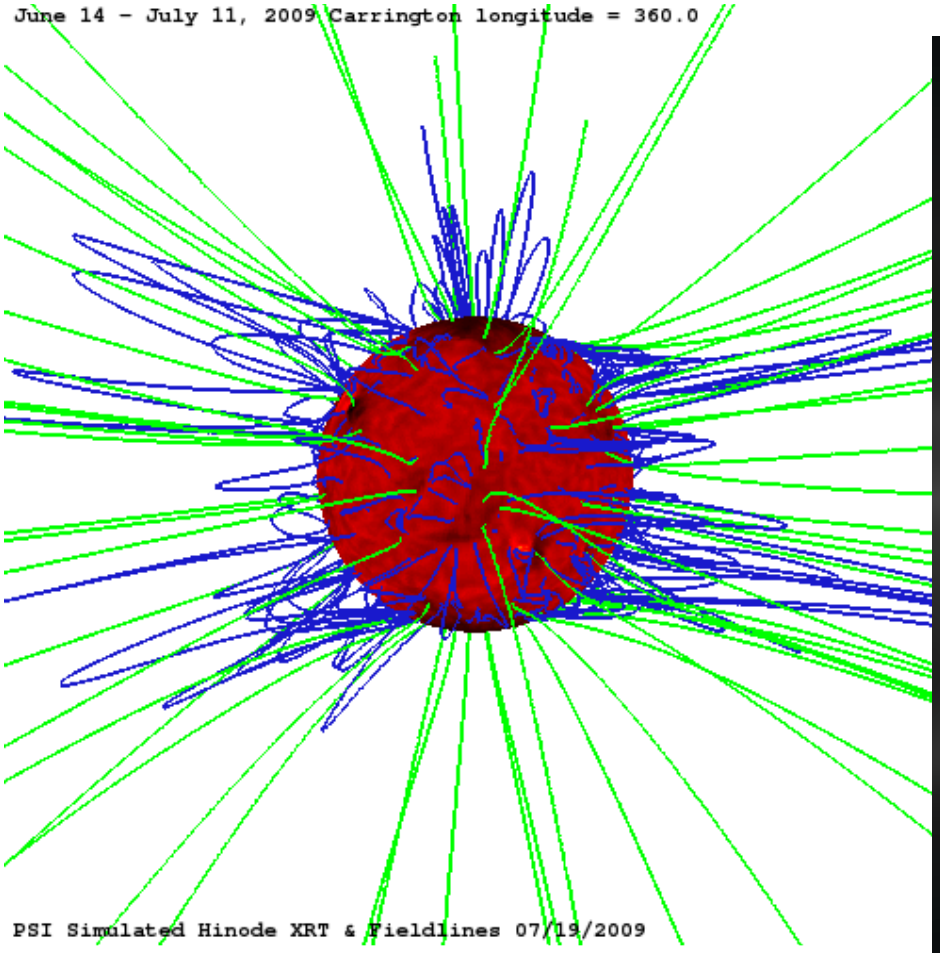


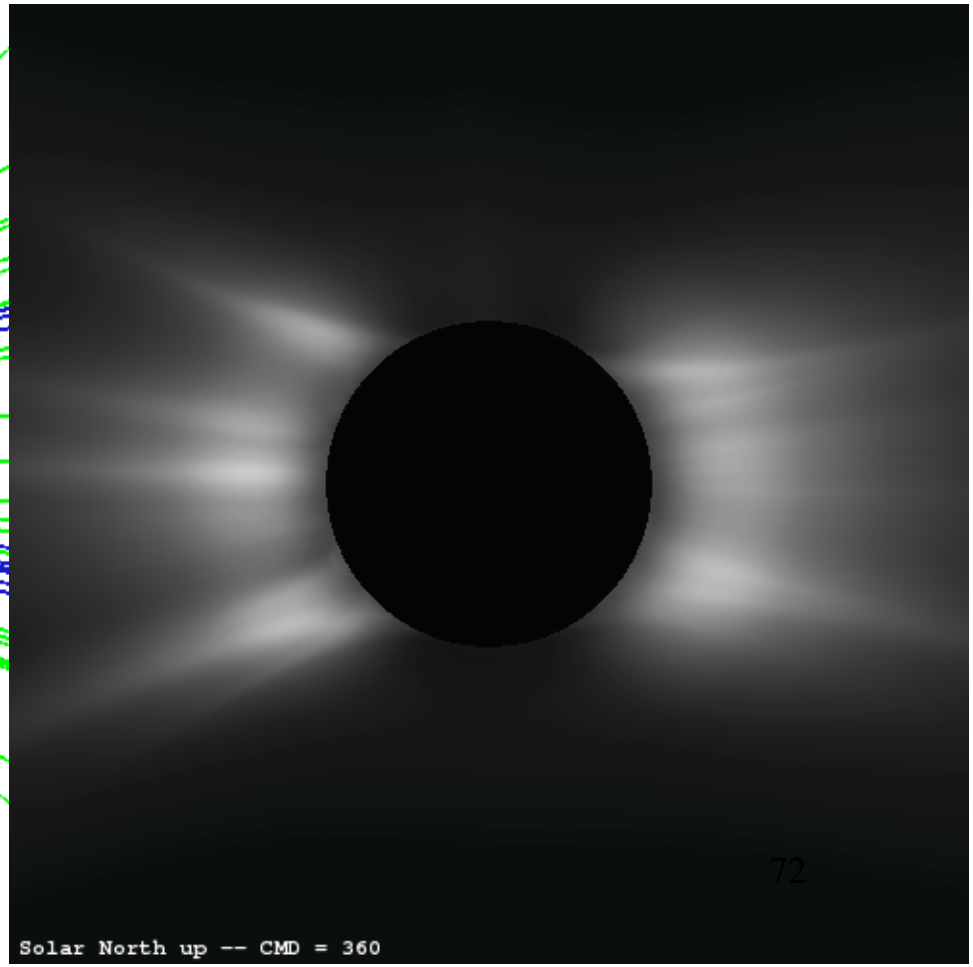
# Current solar minimum: evolution

The fire hose has become a sprinkler head!

June-July 2009 MAS modeled corona

Courtesy Jon Linker




# Summary

- The recent solar minimum was not just deep, but also long and complex
- WHI illustrates certain aspects of this solar minimum well:
  - "Quiet" side irradiance (as low as any this minimum)
  - Low-latitude coronal holes→high-speed streams→geospace periodicities
- The length of this cycle allows us to probe Sun-Earth physical processes

1. In 2008 geospace was forced by high-speed streams, even though solar irradiance, activity, and IMF were lower than 1996 – *allows us to isolate the effects of fast solar wind*
2. In 2009 low-latitude open flux diminished; high-speed streams no longer periodically forced the Earth – *allows us to study the Sun-Earth system at its "quietest"*

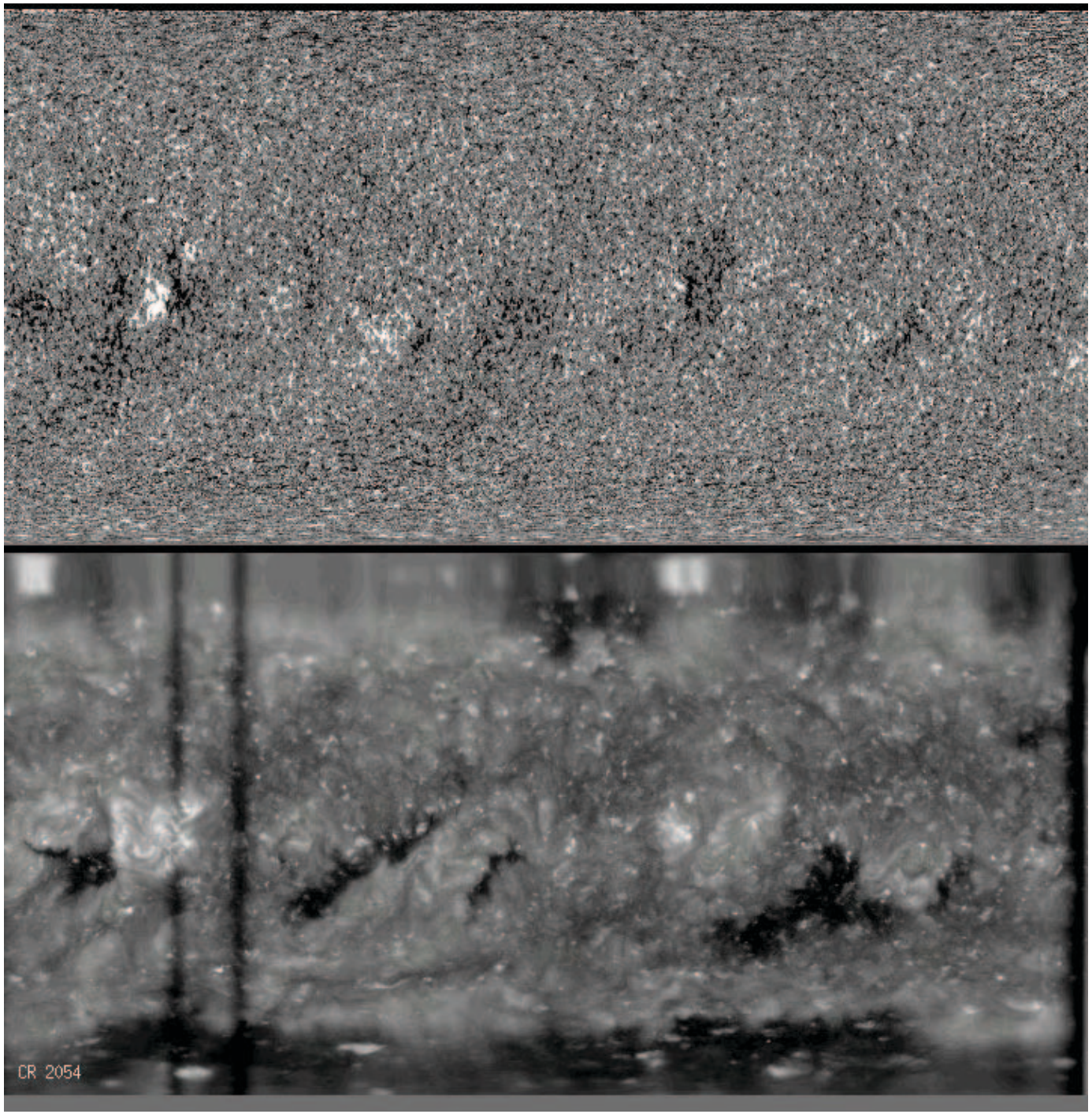
- WHI is a good example of #1 – more end-to-end modeling needed
- Mid-2009 good time to study #2


SOHO-MDI

# Rotations spanning minimum

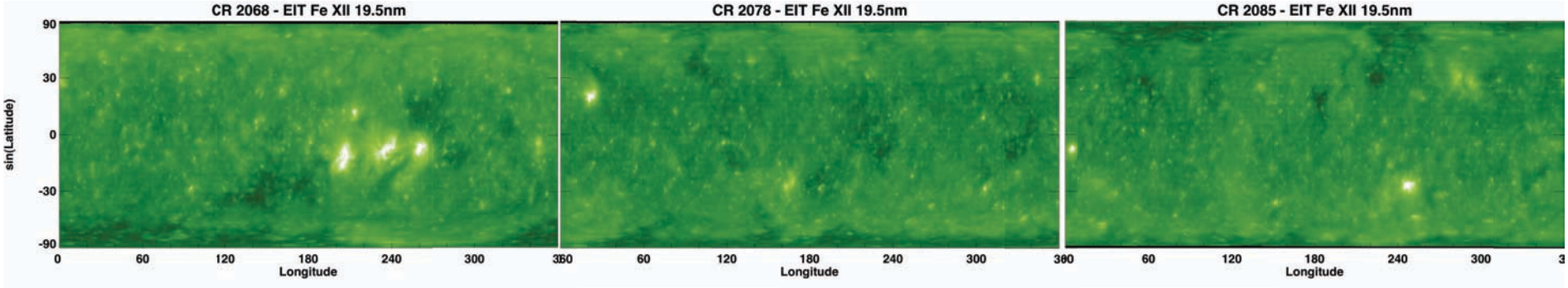
STEREO EUVIA+B

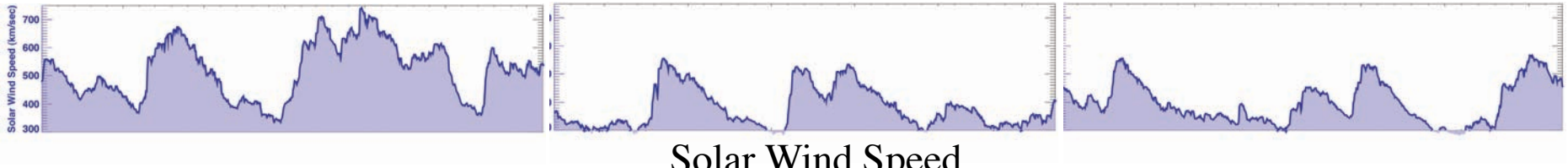
Courtesy Neal Sheeley



# Rotations spanning minimum

Mar 20-Apr 16 08 (CR2068)  Dec 17 -Jan 12 08/09 (CR2078)  Jun 26-Jul 22 09 (CR2085)



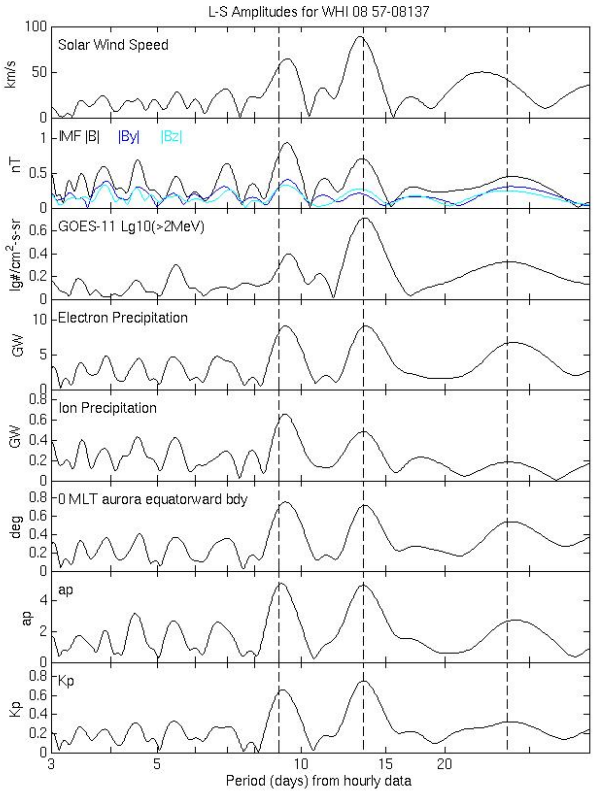

Solar Wind Speed


GOES radiation belt (green) and solar wind pressure (pink)

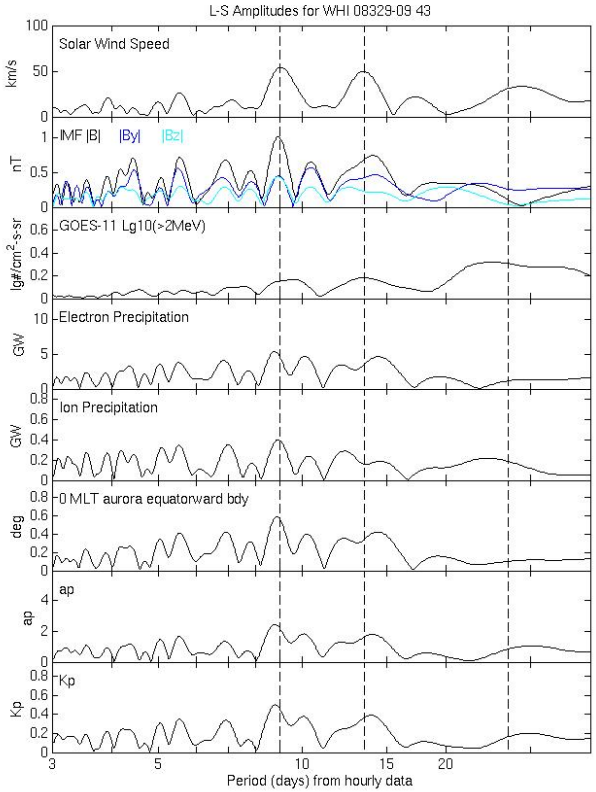
Courtesy Giuliana de Toma, Barbara Emery, Jennifer Gannon

# Rotations spanning minimum

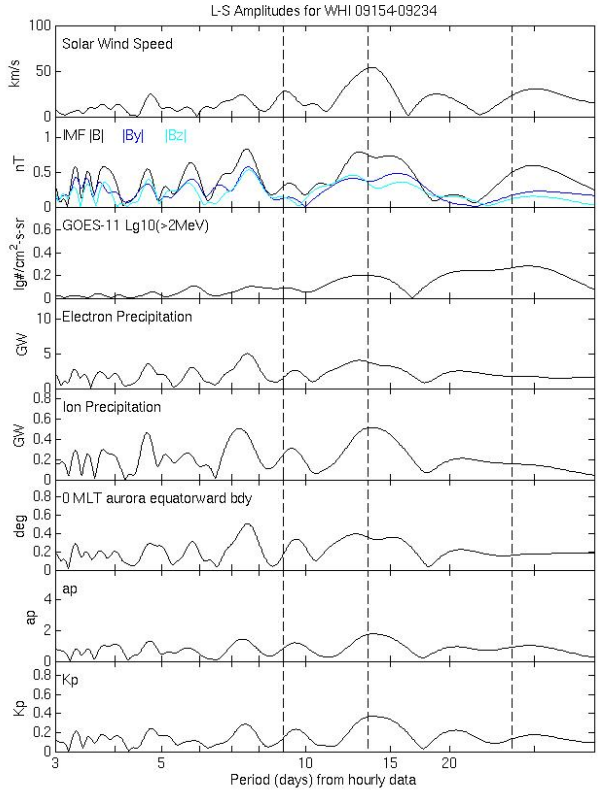
Mar 20-Apr 16 08 (CR2068)




Dec 17 -Jan 12 08/09 (CR2078)




Jun 26-Jul 22 09 (CR2085)




Courtesy Barbara Emery