

The Solar Wind During Grand Minima

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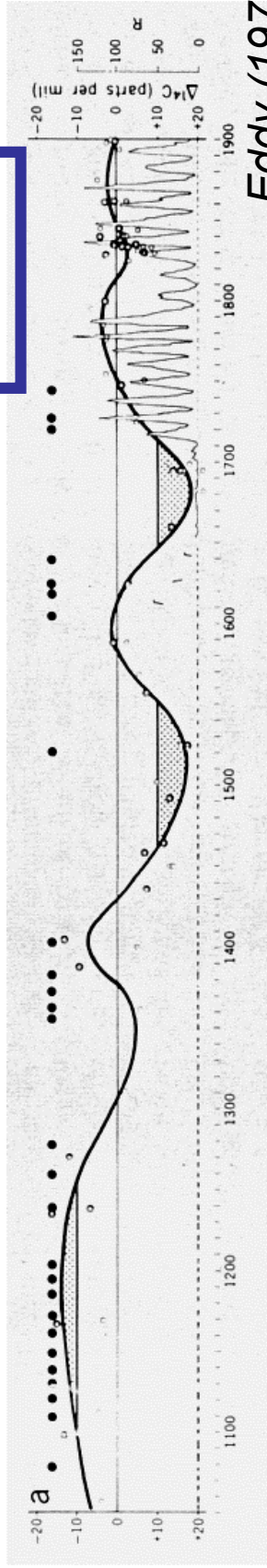
**L. Svalgaard
Easy Tool Kit, Inc.**

**2nd Space Climate Symposium
13-16 September 2006**

Outline

- History
- ~ 130 Years of Solar Wind
 - Interplanetary Magnetic Field (IDV)
 - Solar Wind Speed (IDV & IHV)
 - Density (Quasi-Invariant)
- Solar Wind Floor During Grand Minima
 - Speculation on Nature of Floor
- 1901: A Glimpse into a Grand Minimum?
 - 2007: A Glimpse into 1901?

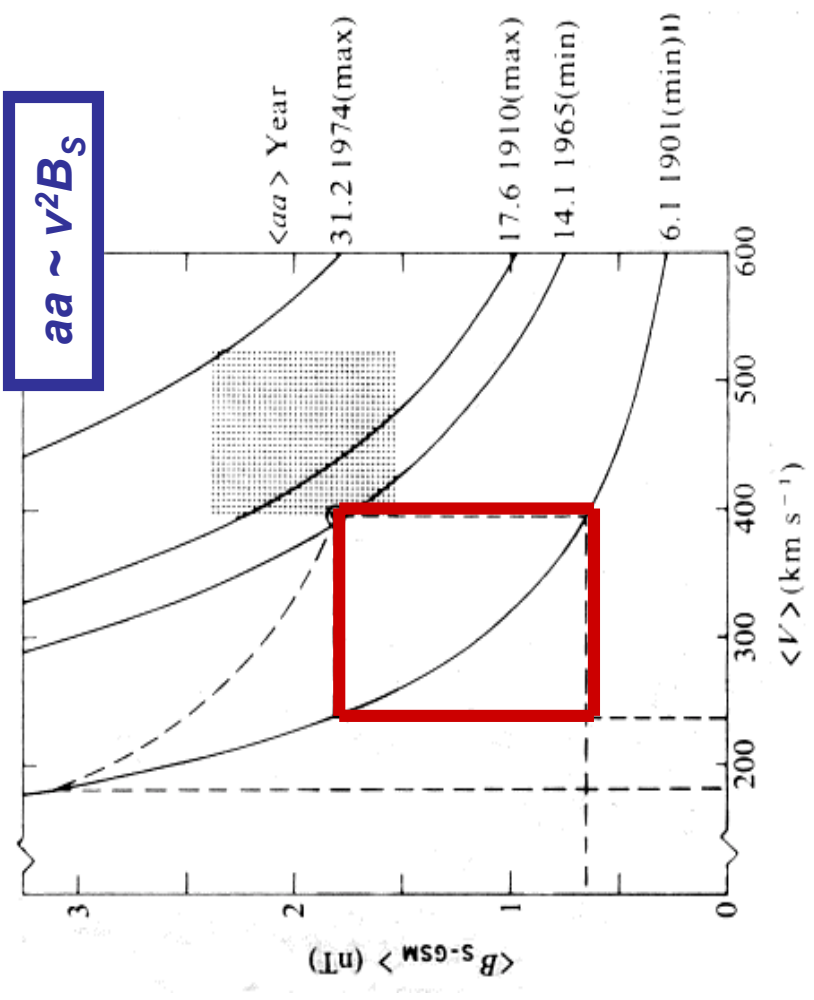
SSN & ^{14}C



Eddy (1976)



Jack Eddy

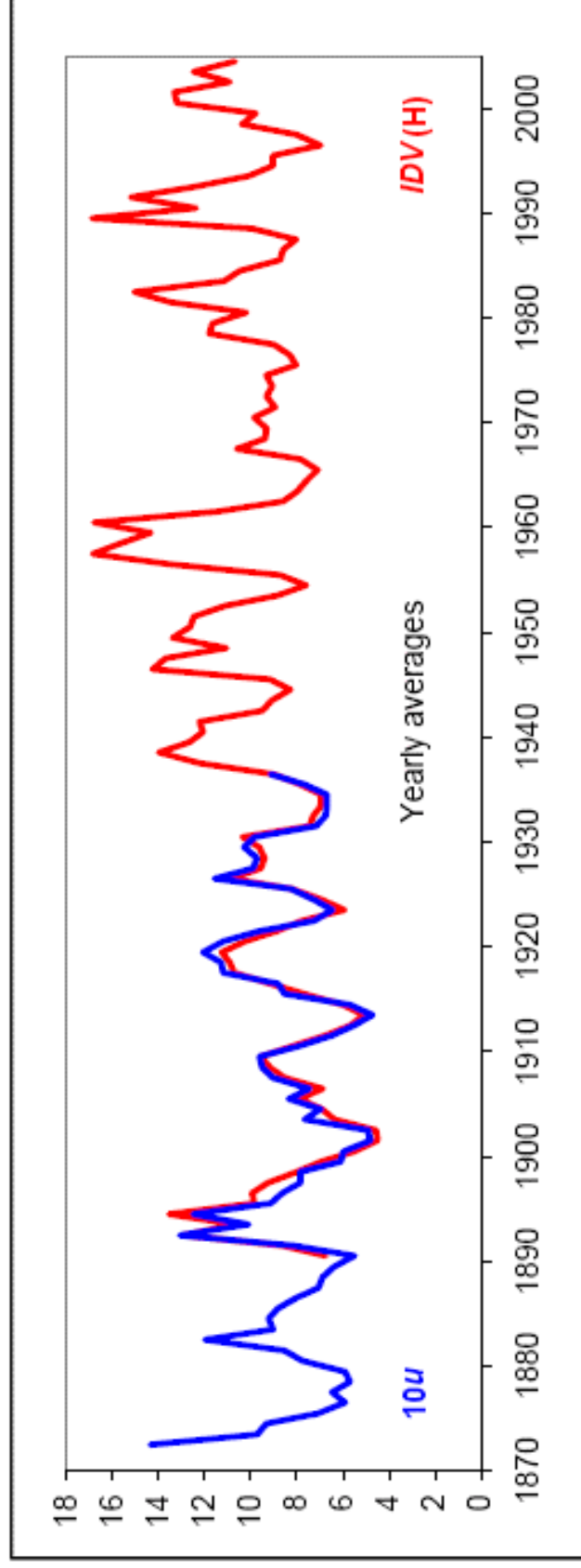


$aa \sim v^2 B_s$

Feynman & Crooker (1978)

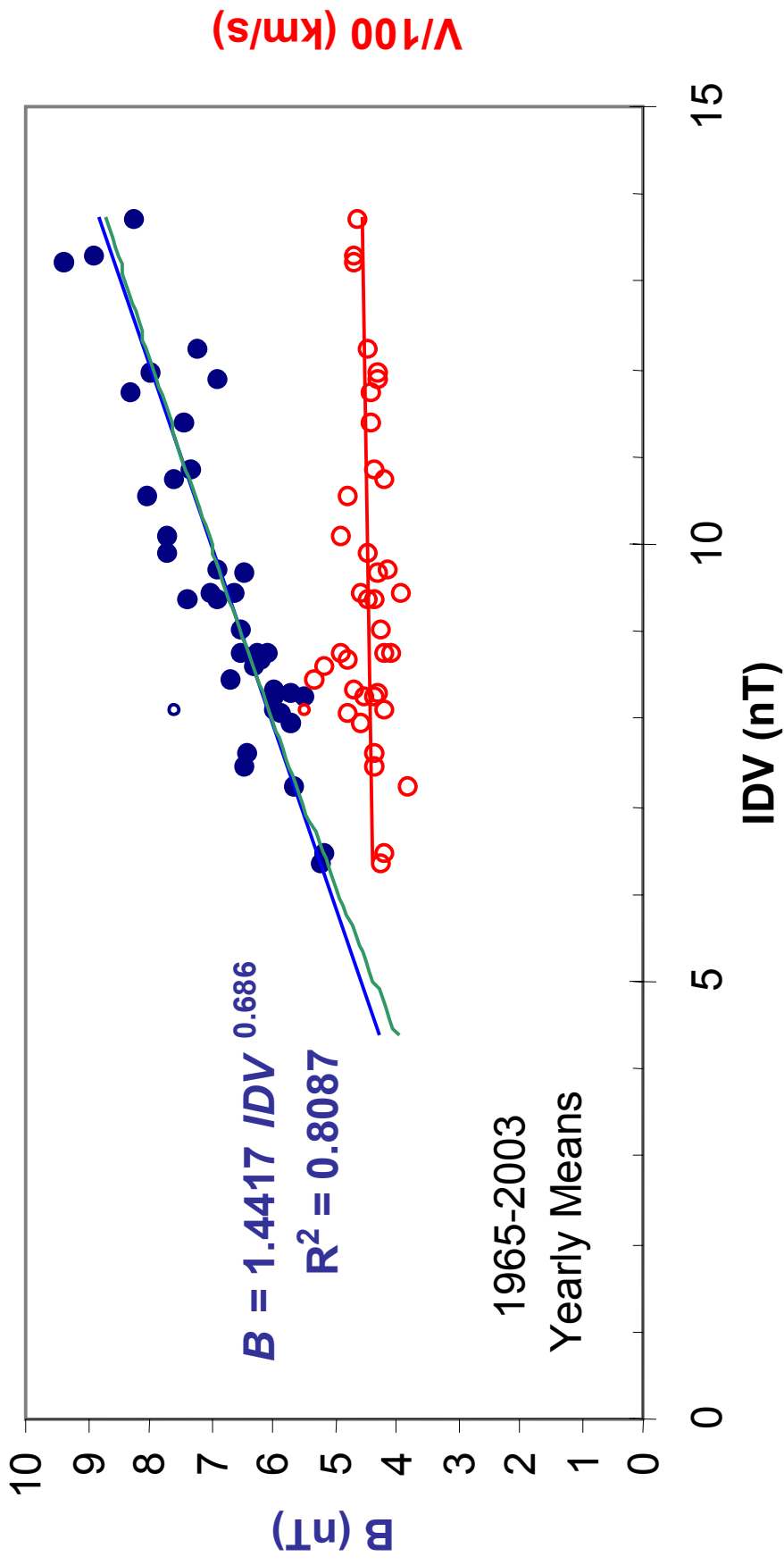
Interdiurnal Variability (IDV) Index

- Based on Bartel's u -index
- Average of absolute values of differences between H-component measured at midnight on consecutive days for low and mid-latitude stations
- Time resolution = 6 months – 1 year
- Available since 1872

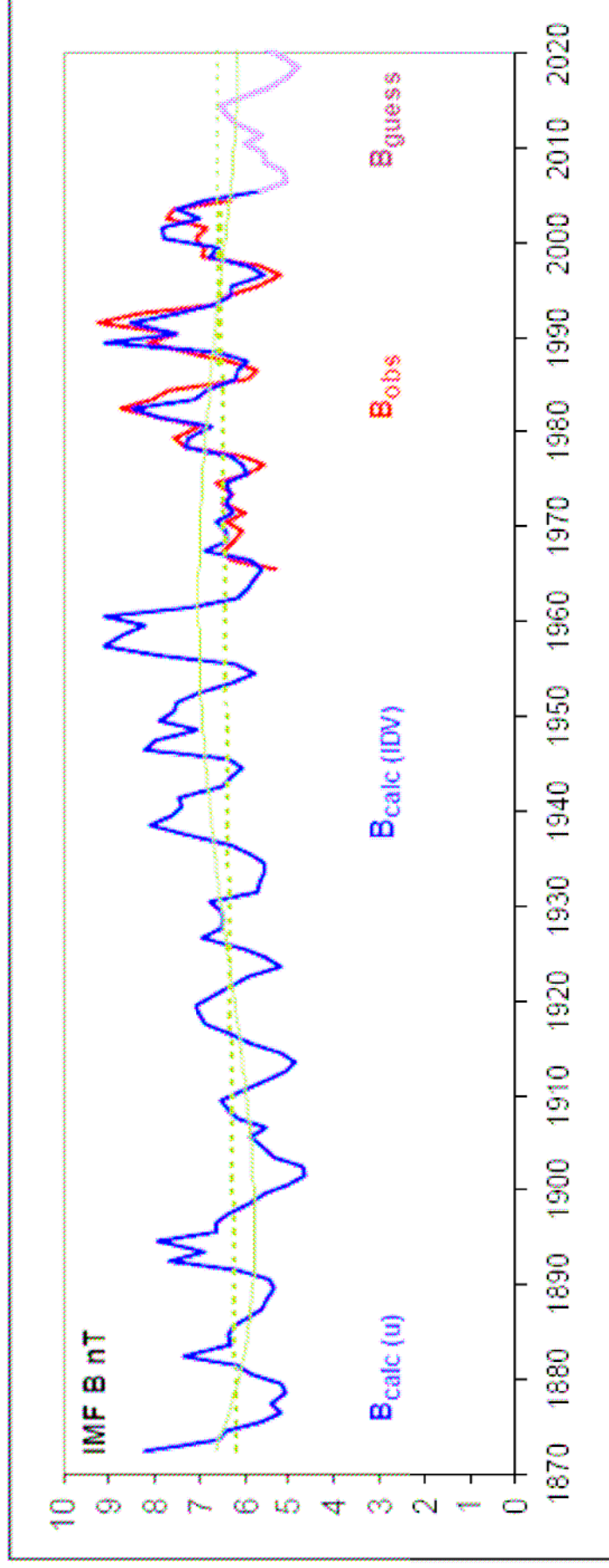


IDV

- Independent of V
- Strongly-Correlated with B

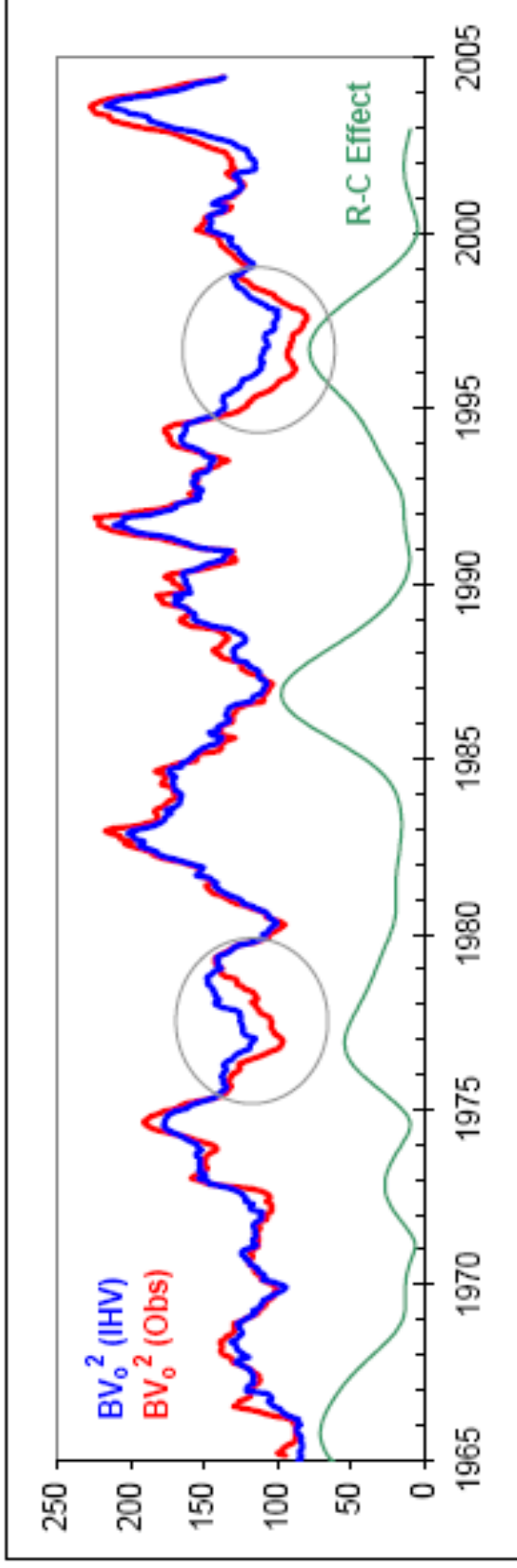


→ B since 1872



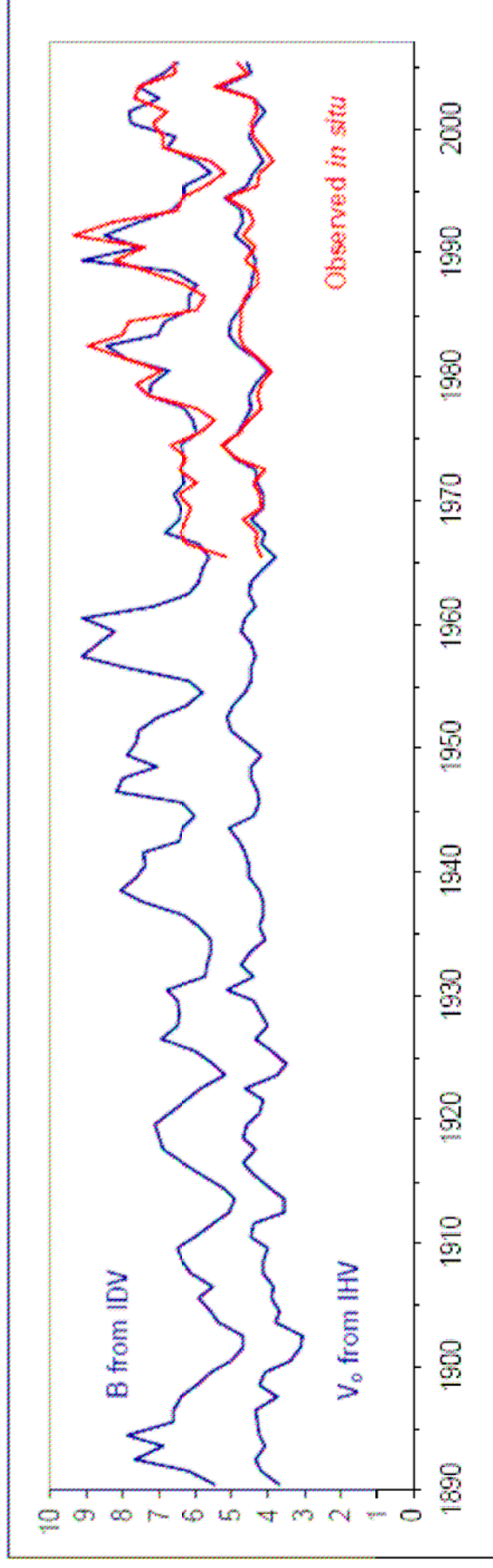
Interhourly Variability (IHV) Index

- Recalibrated *aa* index
- Based on local midnight observations for worldwide mid- and low-latitude stations
- Highly-correlated with BV^2



Two Equations, Two Unknowns

- Solve for $V(IHV)$
- Compute V for years before 1965

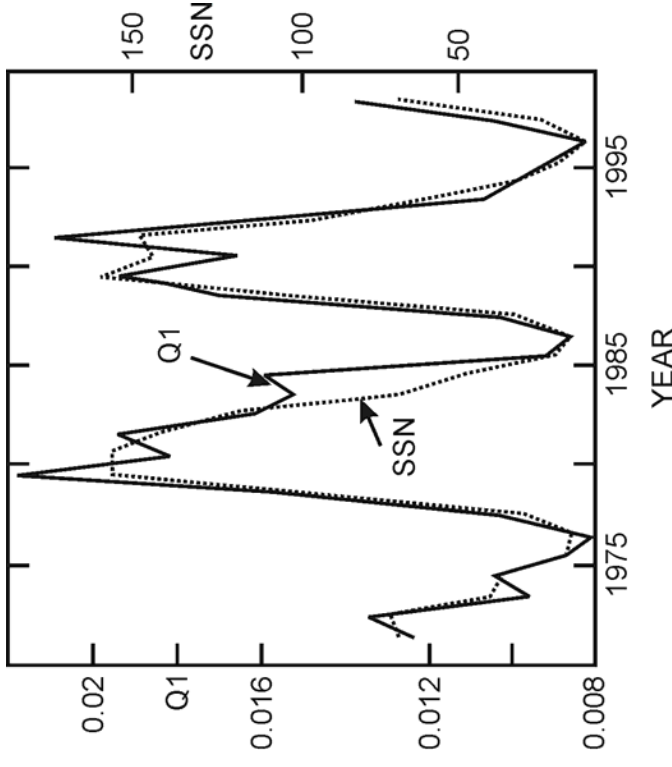


Long-term Variation of Solar Wind Density

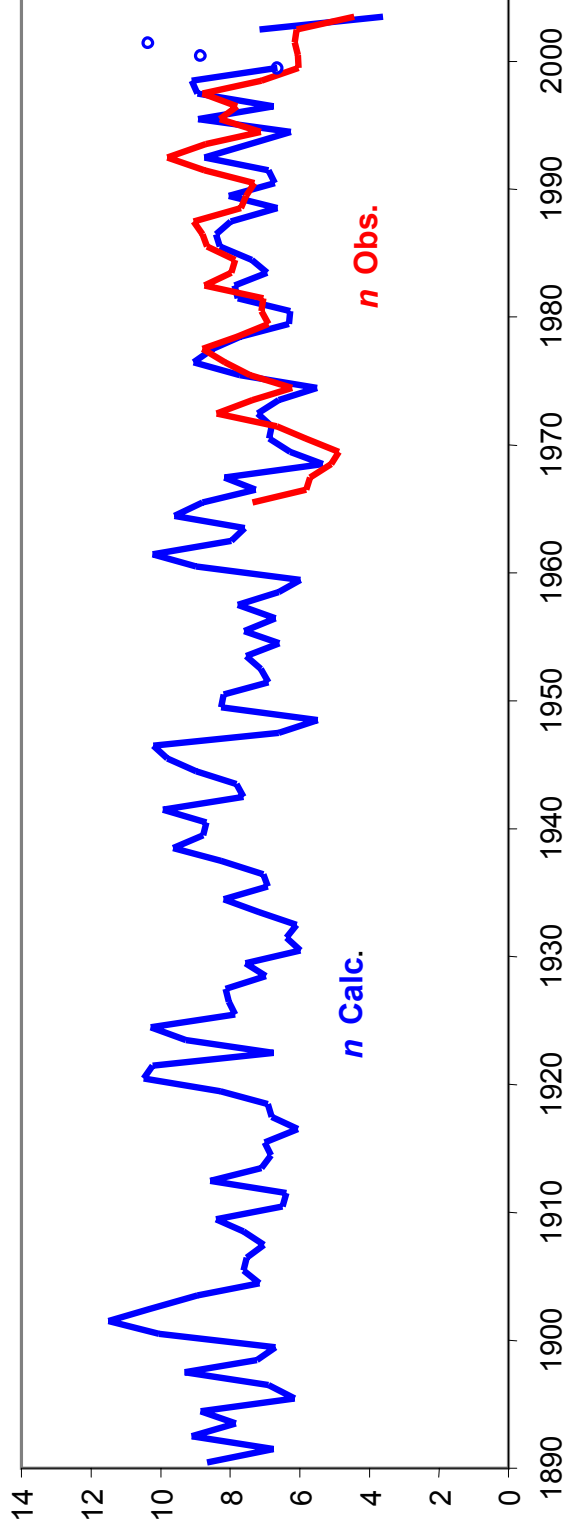
Solar Wind Quasi-Invariant (QI)

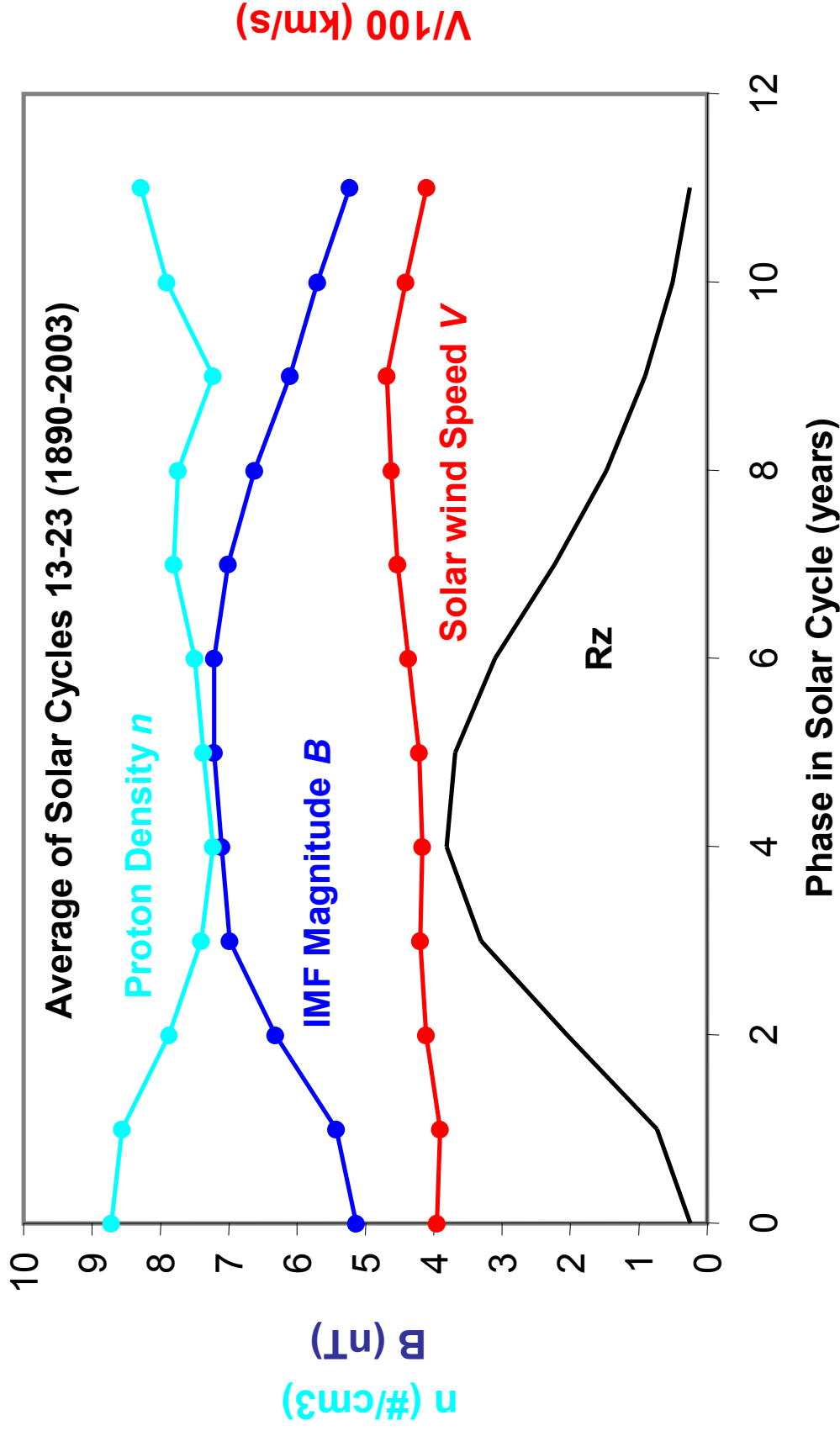
$$QI = (B^2/8\pi)/(pv^2/2)$$

$$SSN = -97 + 12,800 * QI$$




Osherovich, Fainberg, & Stone (1999)



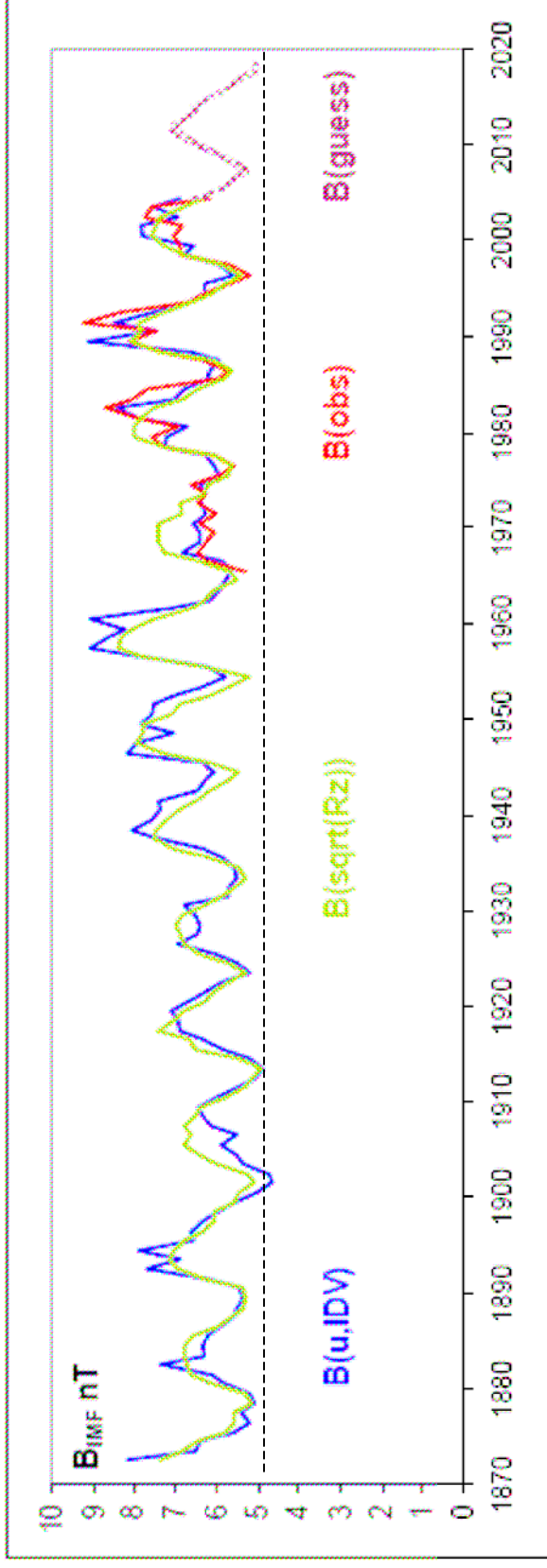
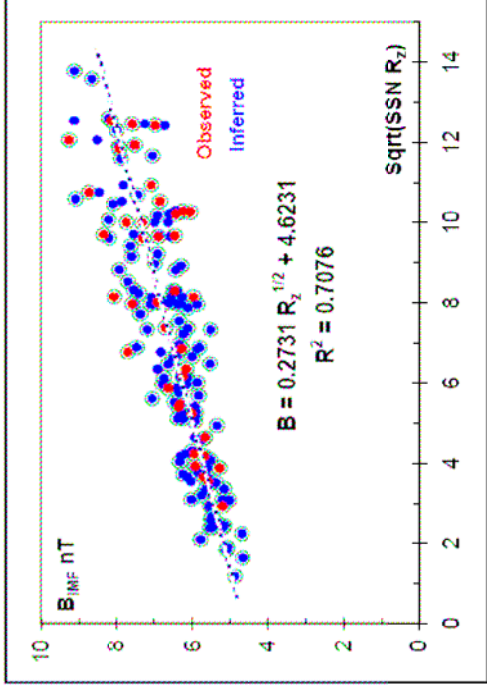


Solar Cycle Variation of Solar Wind Parameters: Superposed Epoch Analysis, 1890-2003

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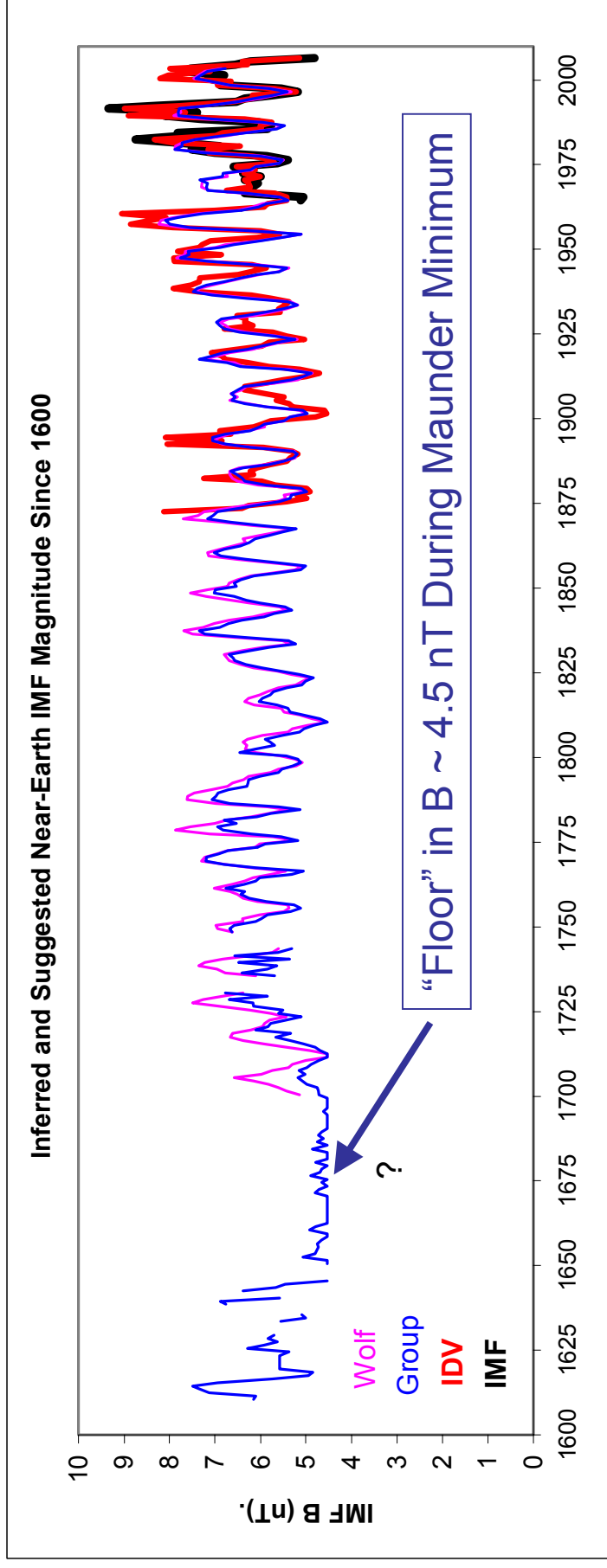
A strong correlation also exists between yearly SSN & B



Combining

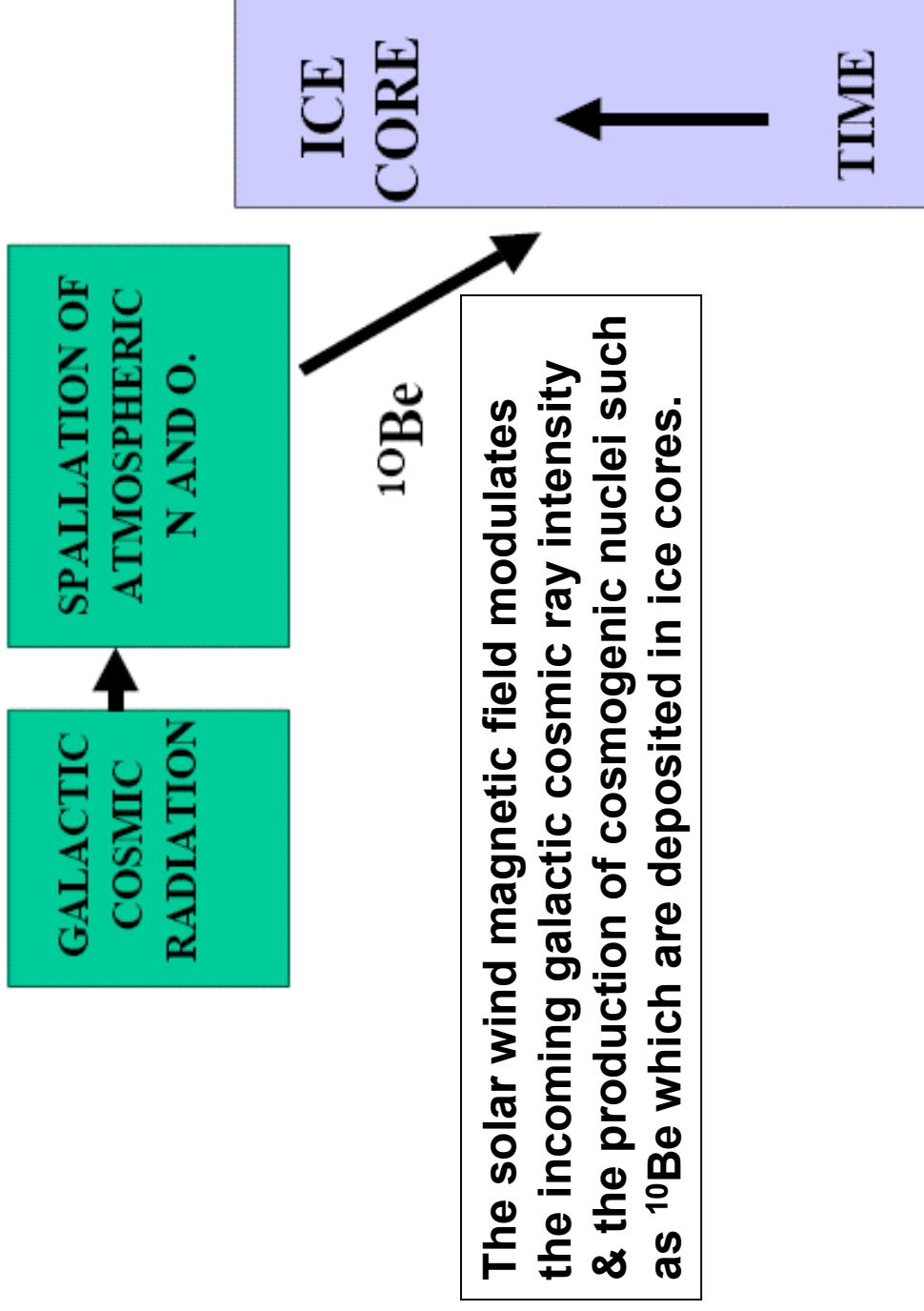
- direct solar wind measurements (1965 - present)
- geomagnetic measurements (1872 - present)
- sunspot observations (1610 - present)

We obtain:



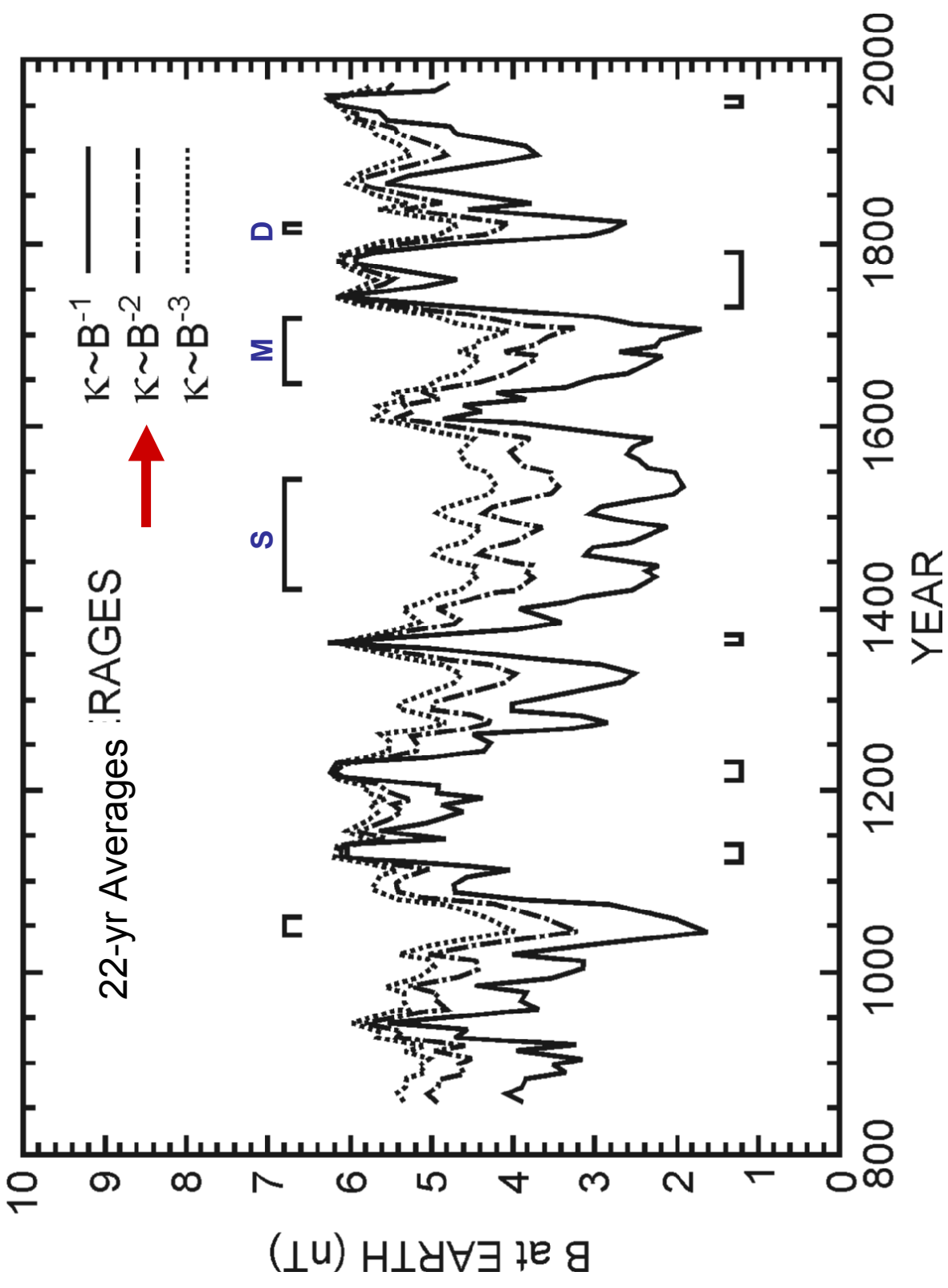
Is it true?

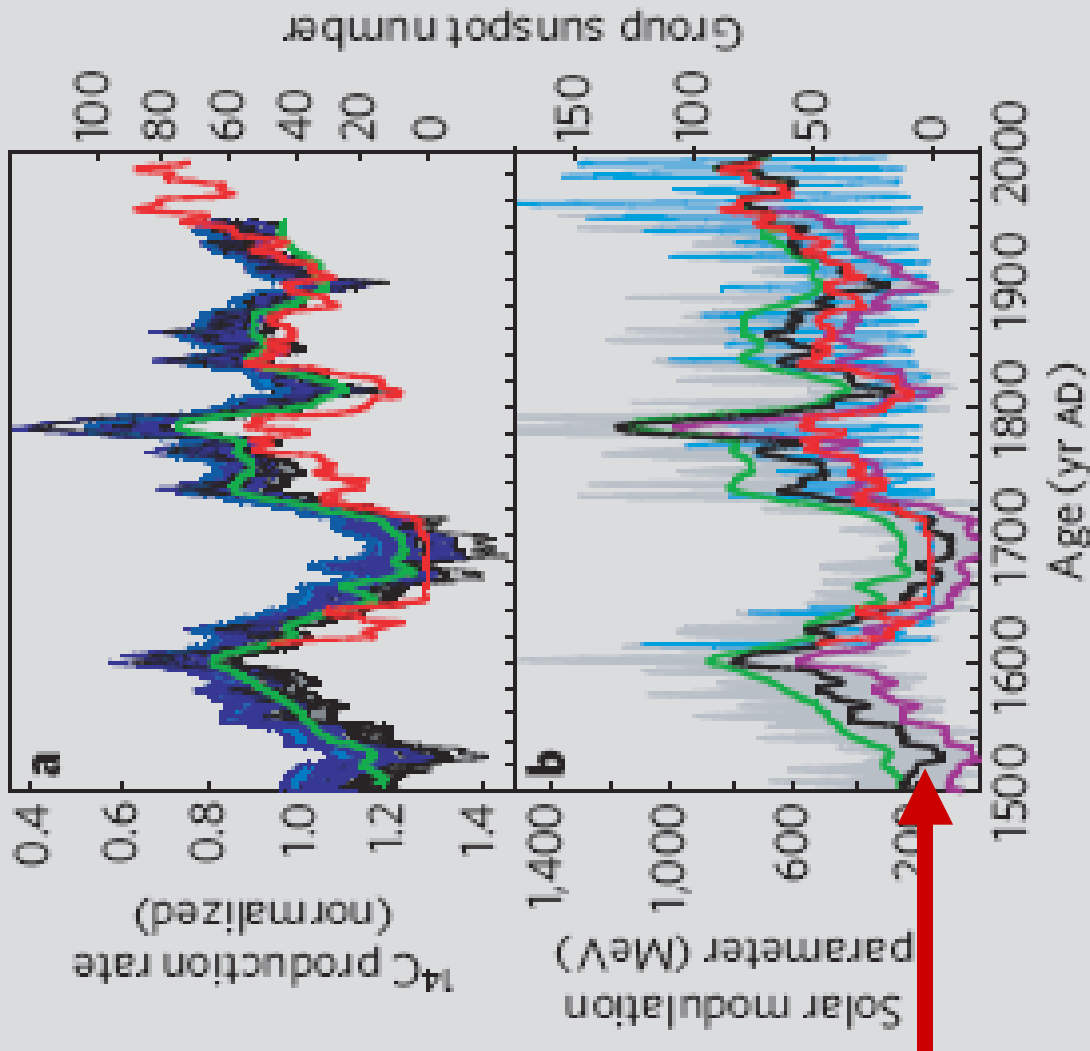
Consistency Checks Using Cosmogenic Nuclei



We compare our inferred ~400-yr time-profile of solar wind B with recent determinations of this parameter (or equivalent) by

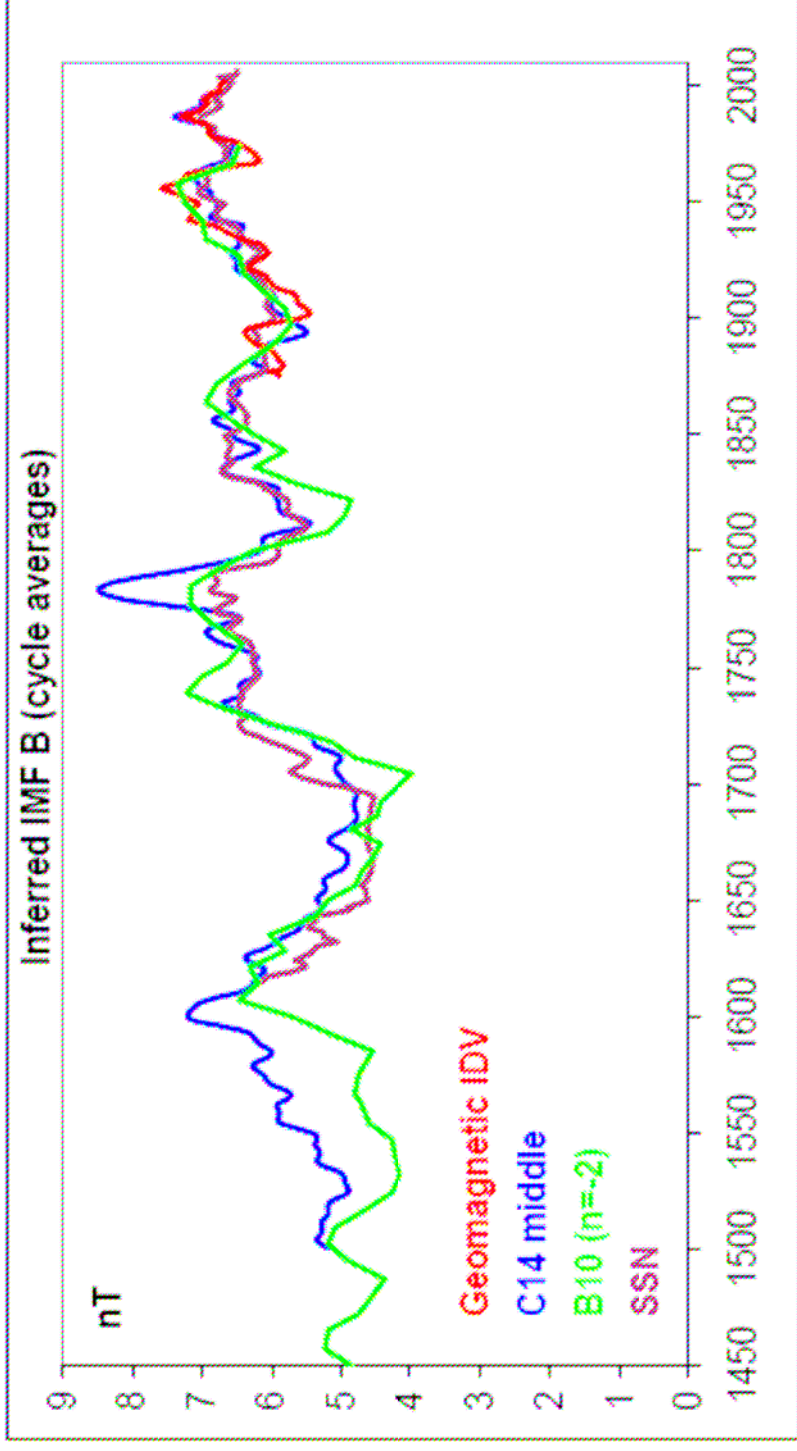
- Caballero-Lopez et al. (2004) (^{10}Be)
- Muscheler et al. (2005) (^{14}C)





**“Best Case”
Model**

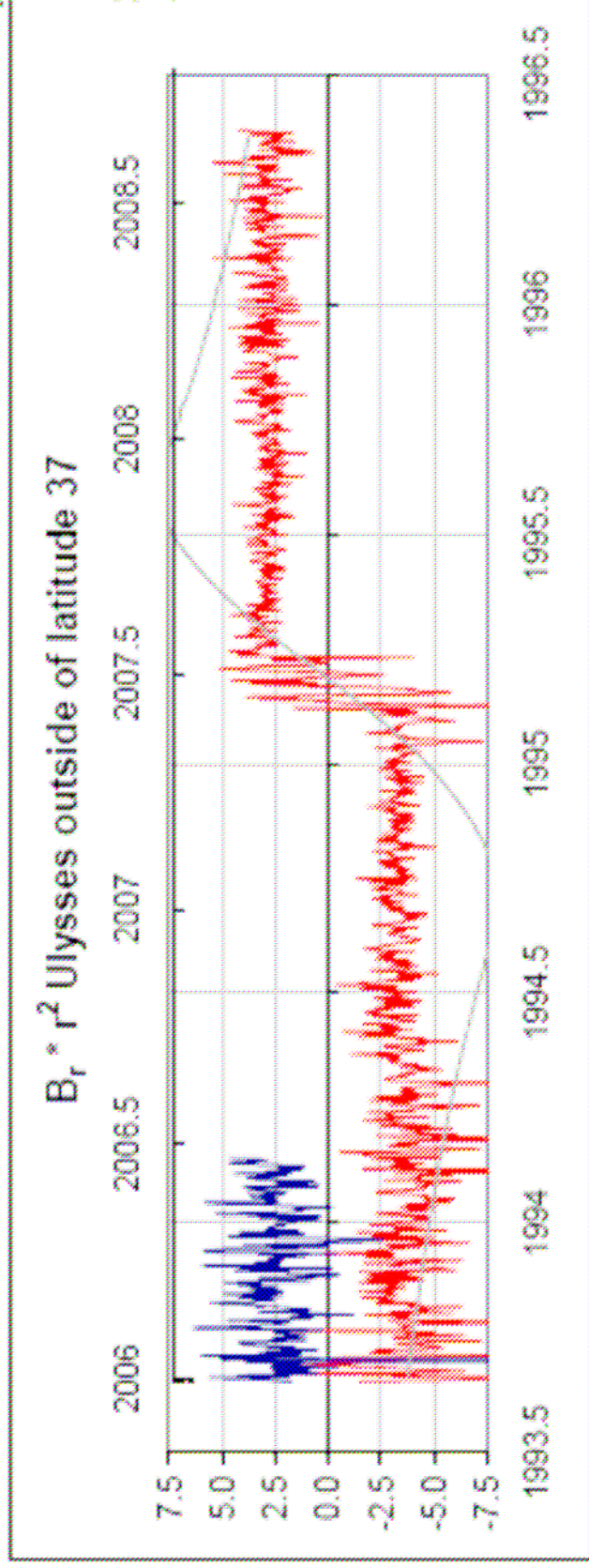
Reconstructions of Solar Wind B



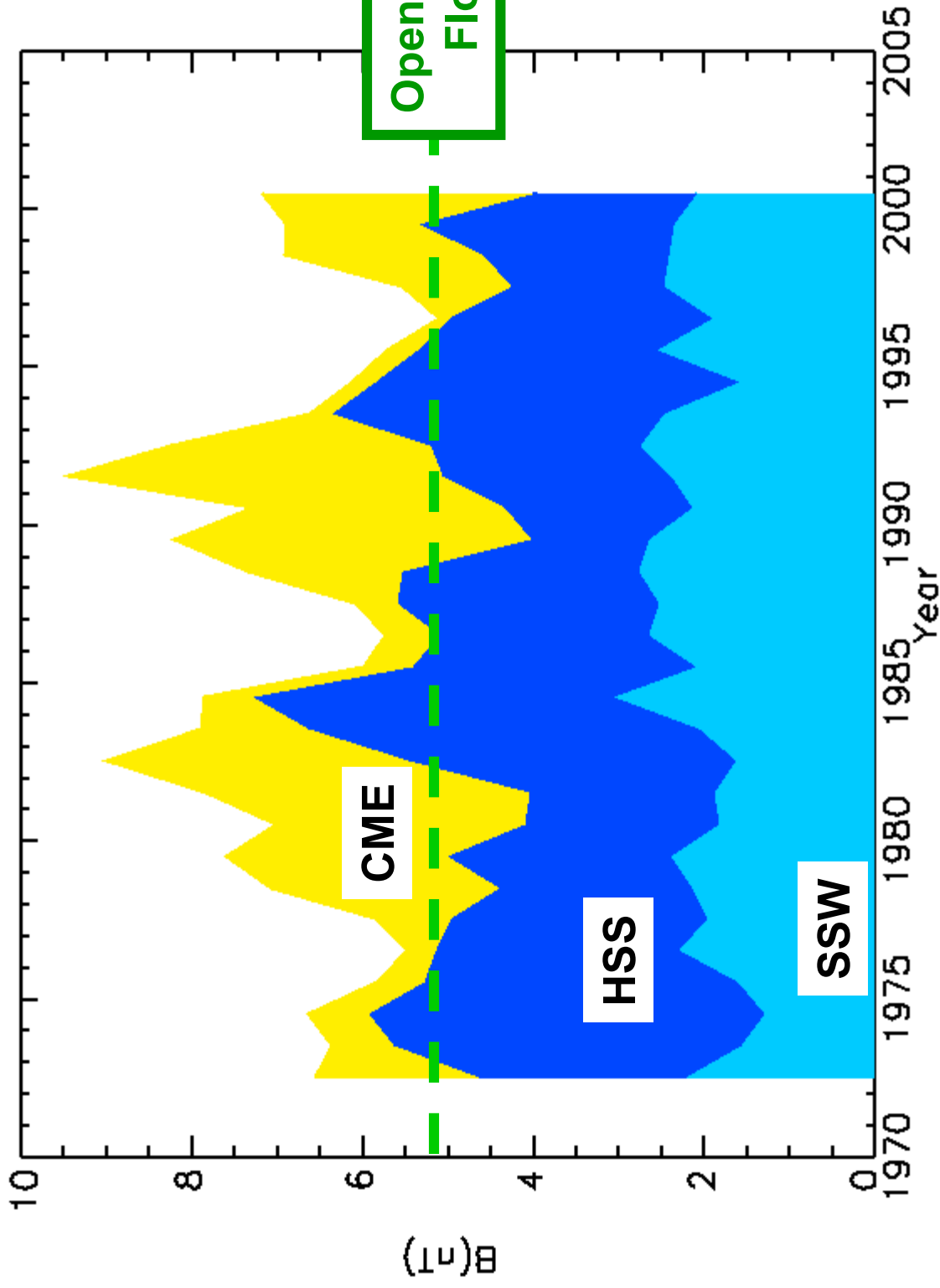
“Floor” in Solar Wind B of ~ 4.5 nT

What is the Source of the Floor?

Floor in B is due to solar open magnetic flux, constant in latitude & time.




Ulysses at Solar Minimum: 1994-1996, 2006

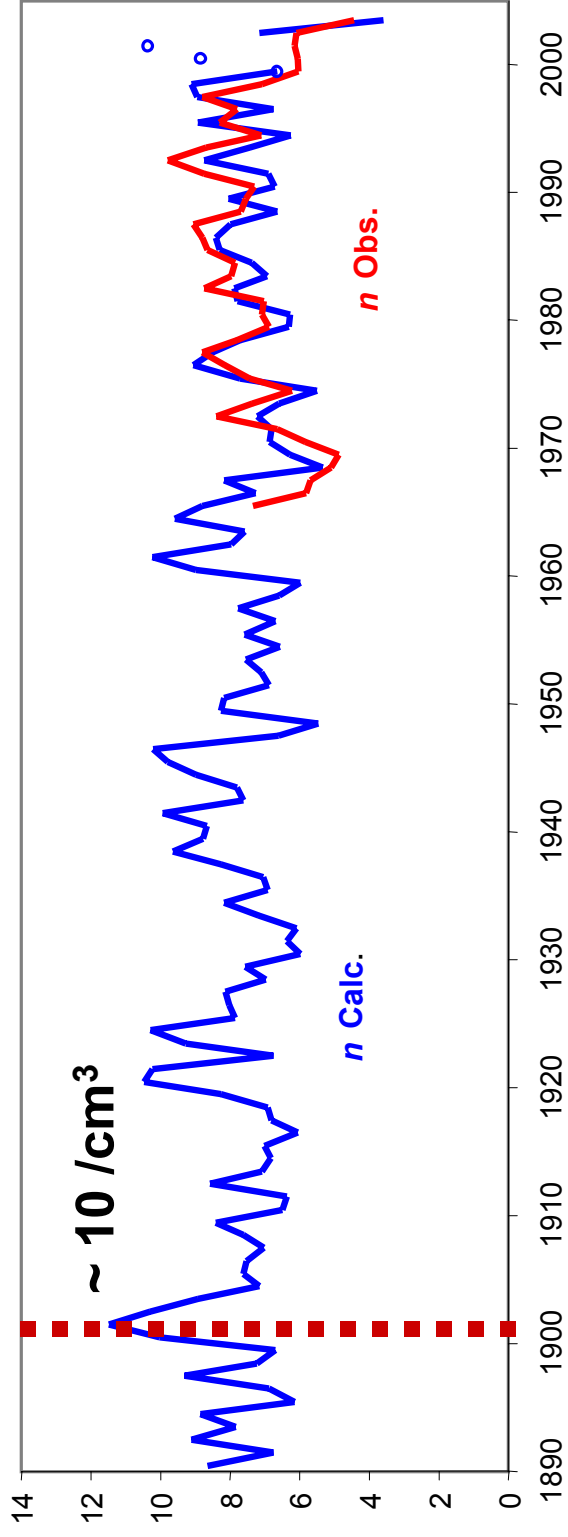
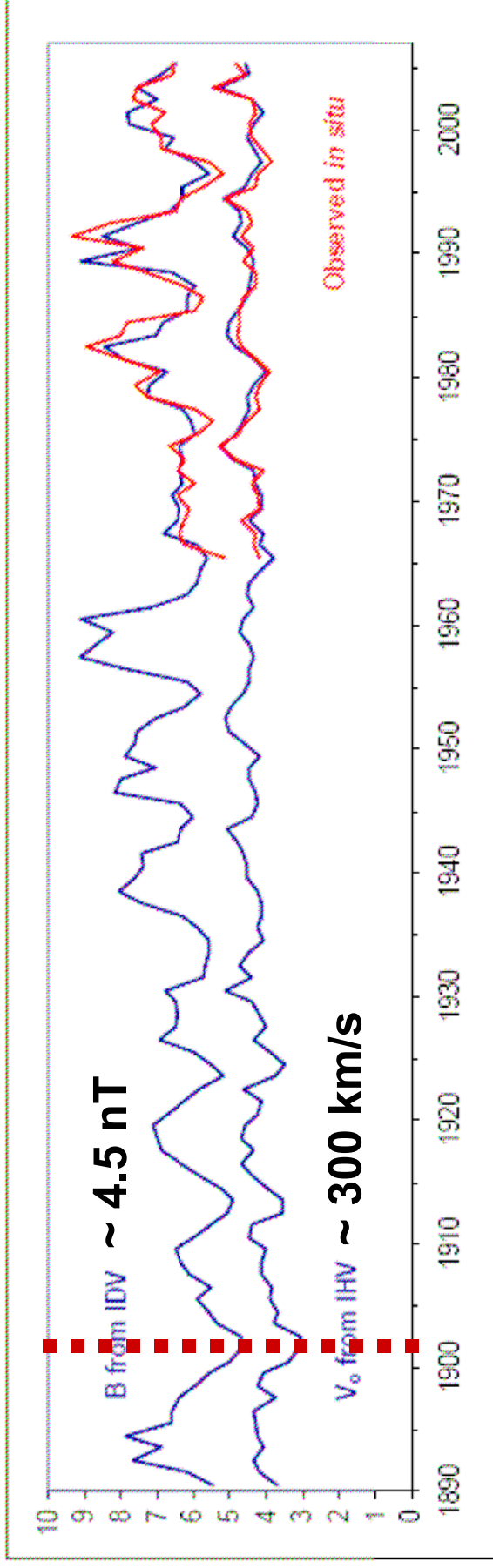


In this scenario, the solar cycle variation of B which sits on top of the floor is due to coronal mass (magnetic) ejections.

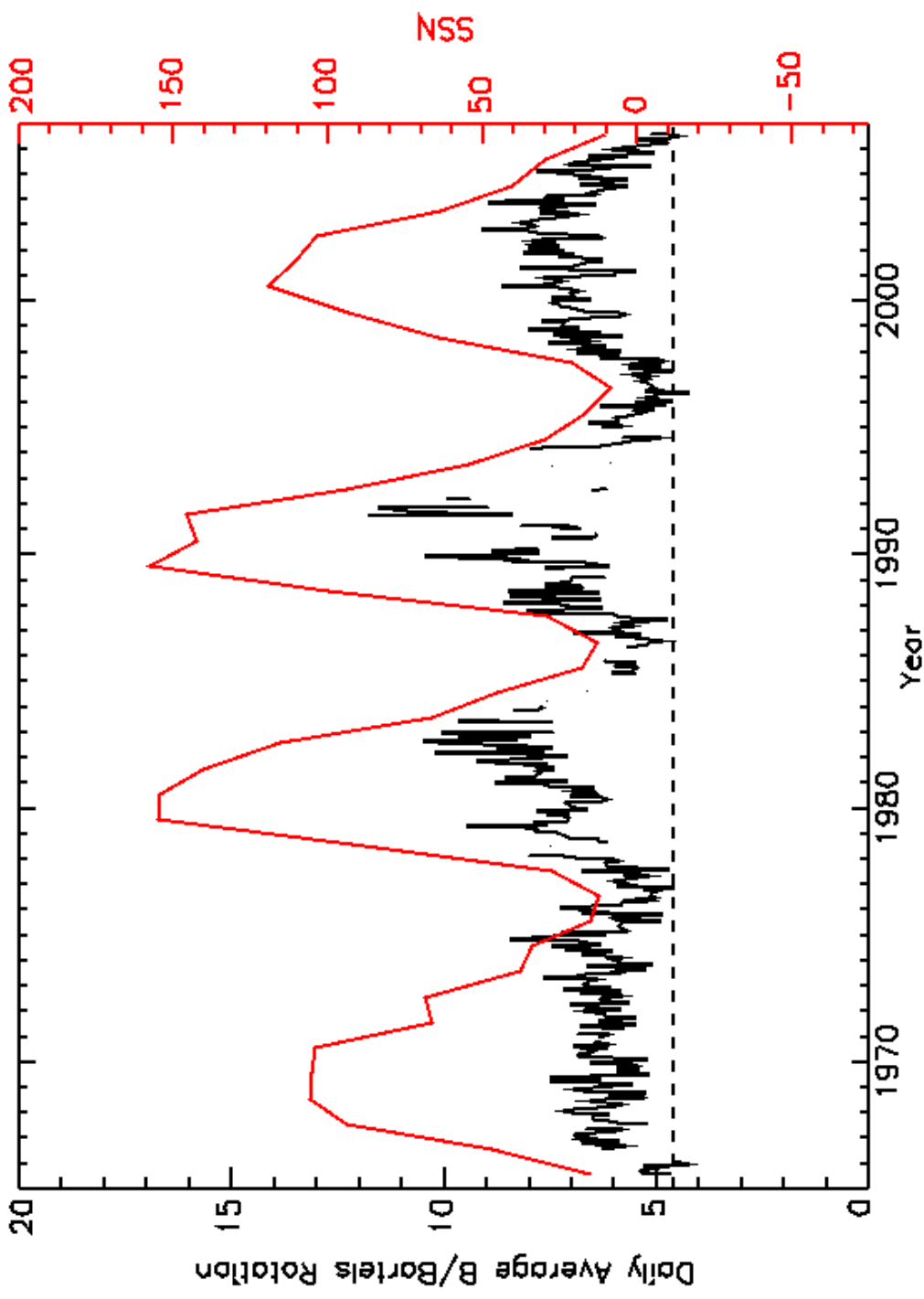
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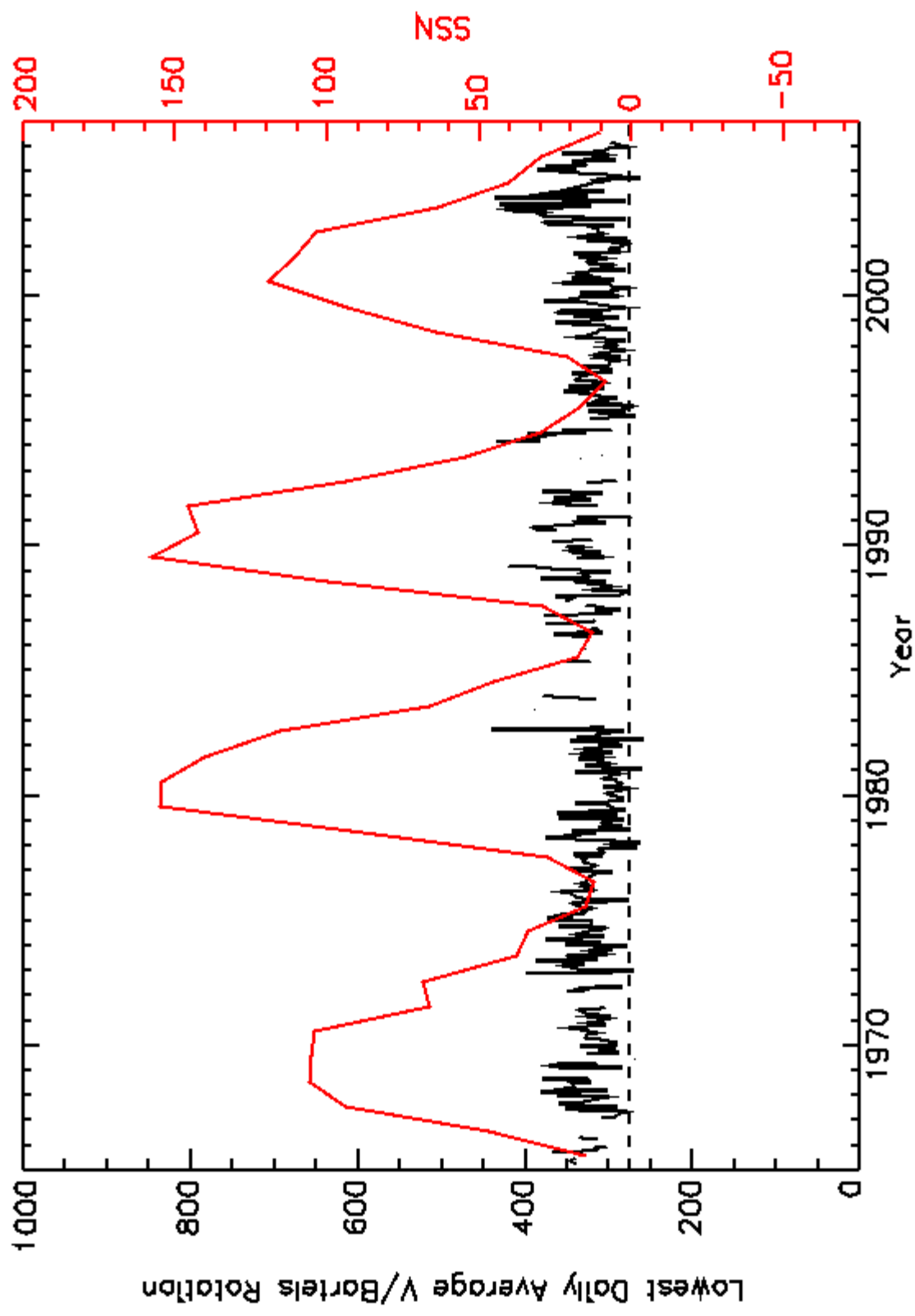
Inferred Solar Wind in 1901



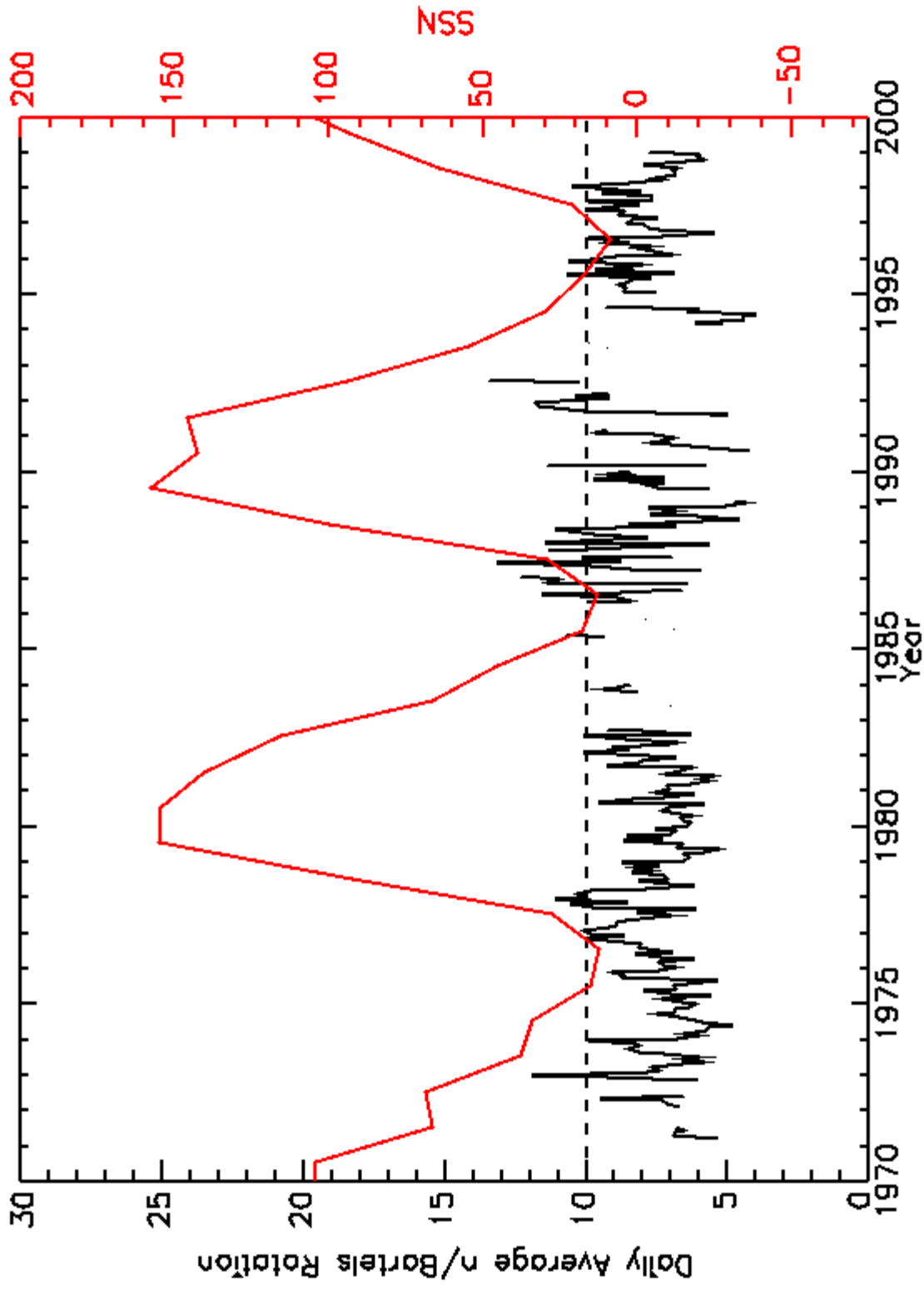
Modern Evidence for Floor in Solar Wind B



Modern Evidence for Floor in Solar Wind V



Modern Evidence for Ceiling in n



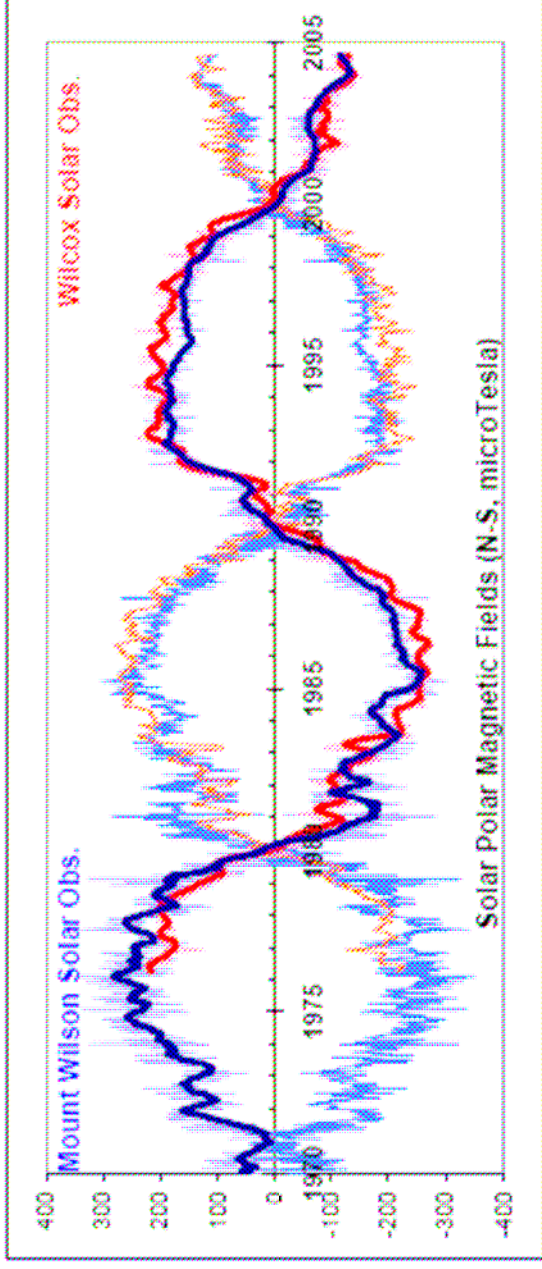
Solar Wind During Grand Minima

$B \sim 4.5 \text{ nT}$

$V \sim 300 \text{ km/s}$

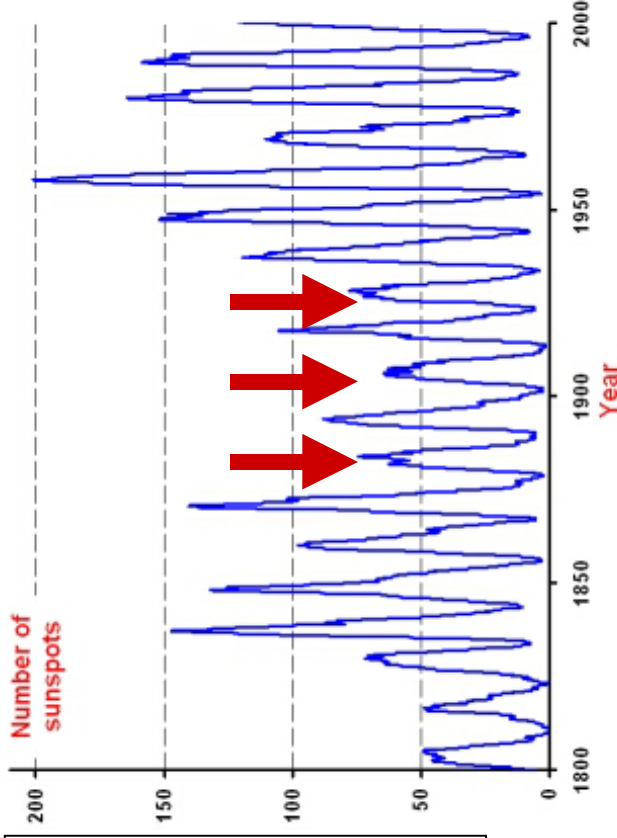
$n \sim 10/\text{cm}^3$

Are we entering a Gleissberg Minimum?

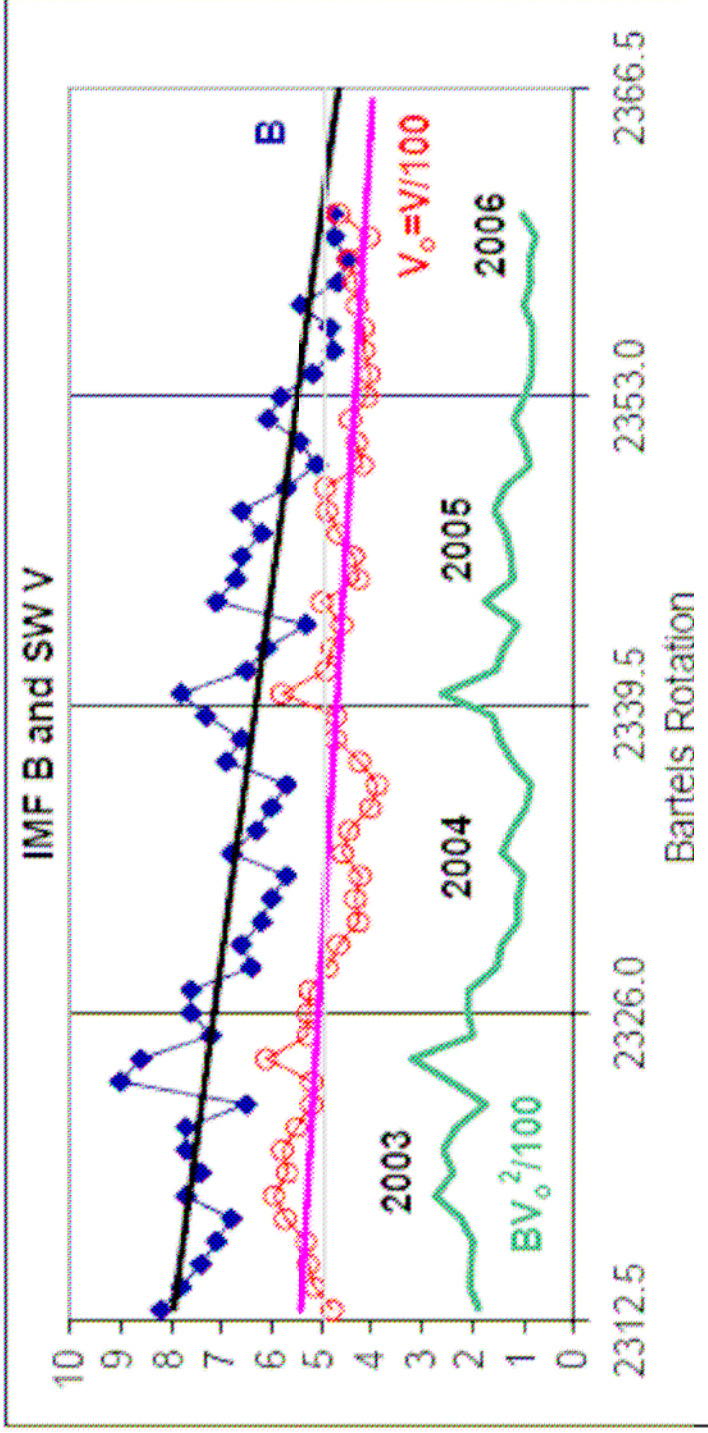


Weak polar fields at current solar minimum → smallest Sunspot Cycle in 100 Years (SSN ~ 75), comparable to Cycles 12 (1884), 14 (1907) and 16 (1928) during the most recent Gleissberg Minimum

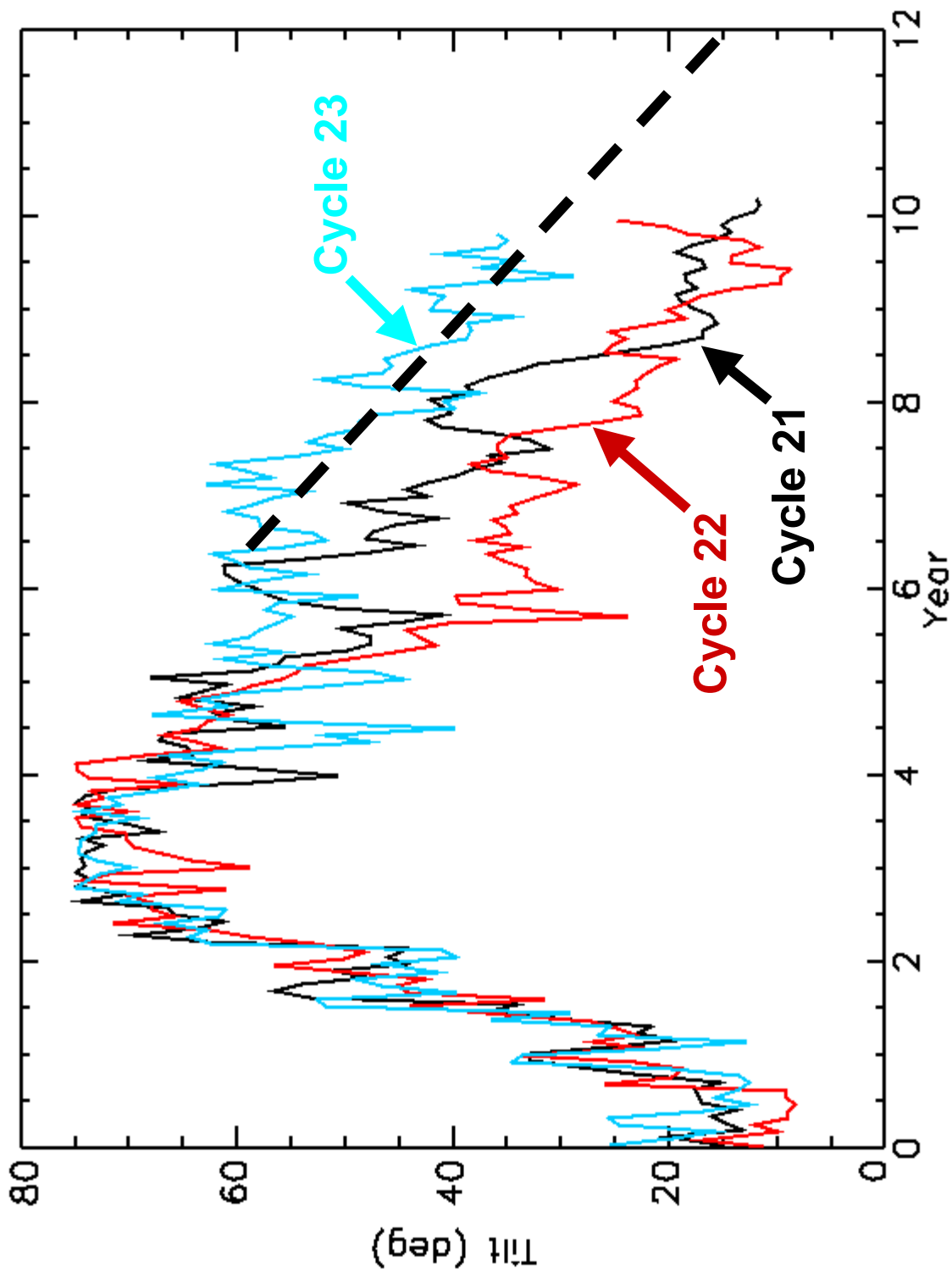
Svalgaard, Cliver, & Kamide (2005)



Recent Solar Wind Data



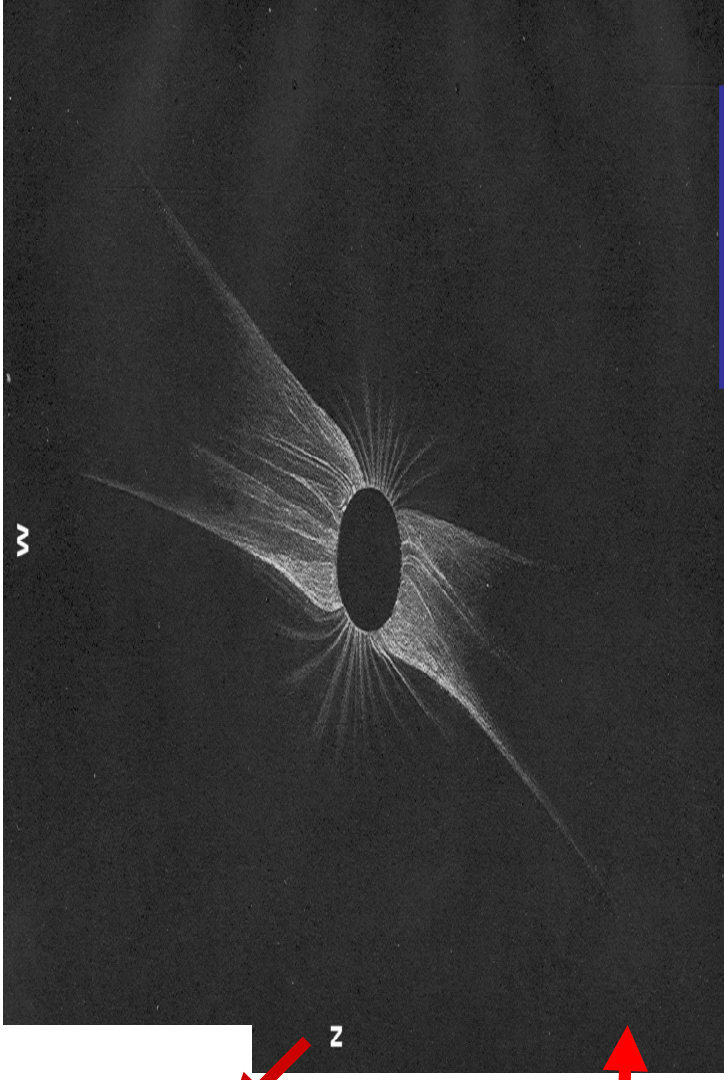
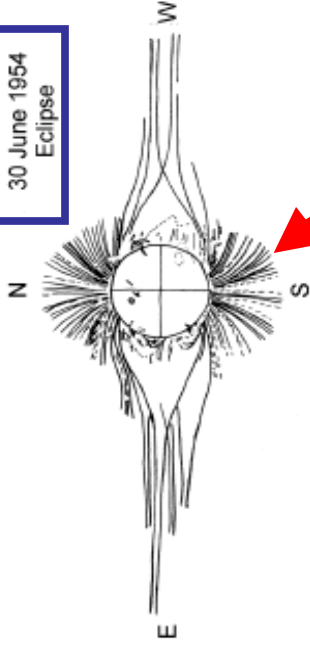
Tilt Angle Variation During Cycles 21-23



Appearance of Corona During Grand Minima

Parker (1975) and Eddy (1976) suggested the Sun might have approximated a single large coronal hole with a “gale force” wind blowing in all directions

30 June 1954
Eclipse



18 May 1901

Does the corona look like this or this at GM?

Conclusions

- Reconstruction of Solar Wind B to ~1600
- Solar Wind “Floor” During Grand Minima
 - $B \sim 4.5$ nT
 - $V \sim 300$ km/s
 - $n \sim 10/\text{cm}^3$
- “Floor” Identified with Constant Open Flux
- 1901 & 2007: A Glimpse into GM?

Back-Up Slide

