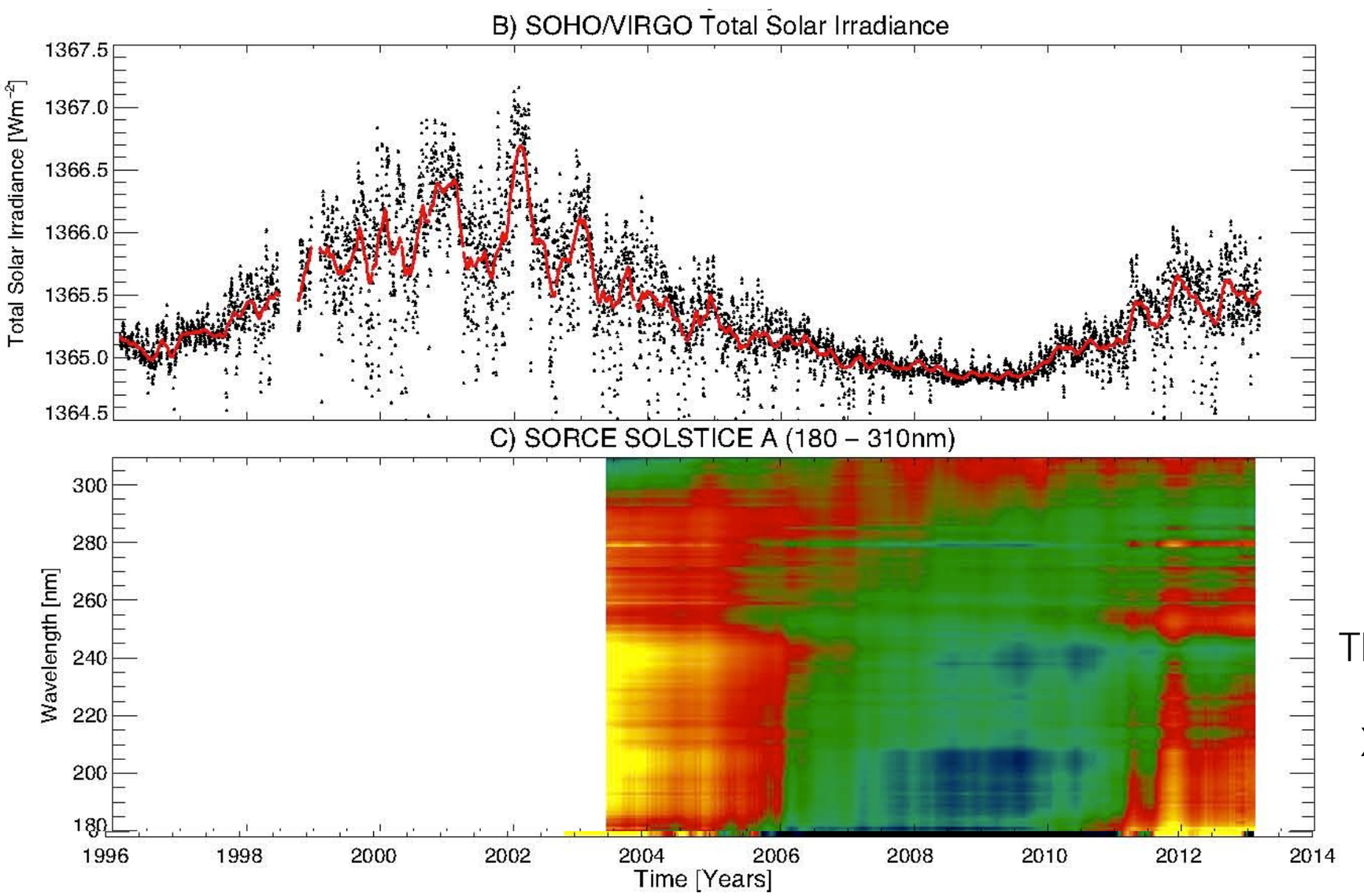
Quasi-Periodic Variations in Radiative Output Driven By Activity Band Interaction



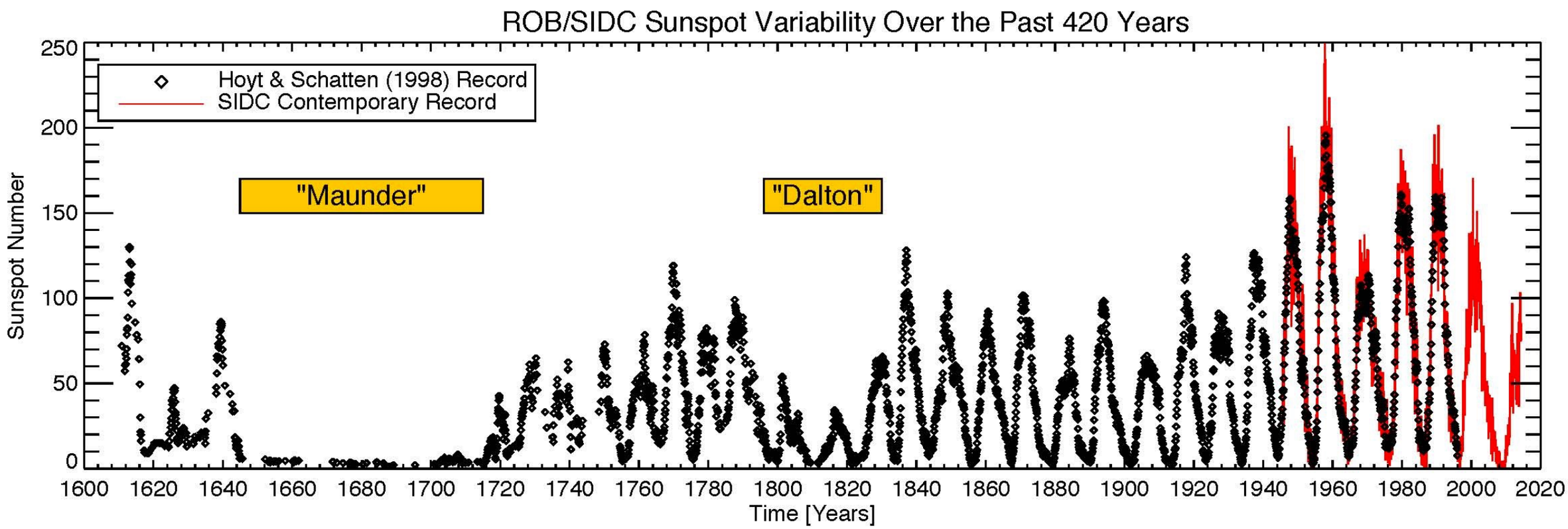
Scott W. McIntosh
NCAR/HAO

Thanks to:
Bob Leamon, Anny Malanushenko, Xin Wang, Marty Snow, Greg Kopp, Jerry Harder, Dan Marsh

Variability in Activity: Living With A Star

We live in the atmosphere of our star.

As a civilization* we take our star for granted.



A question that motivates us…..

….what will it do….

…over coming centuries?

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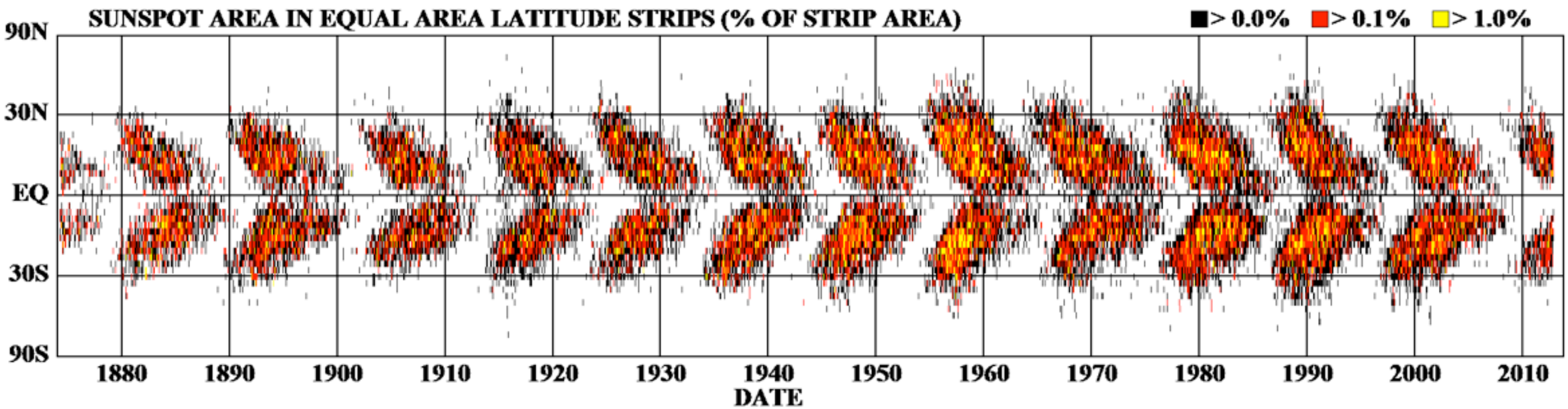

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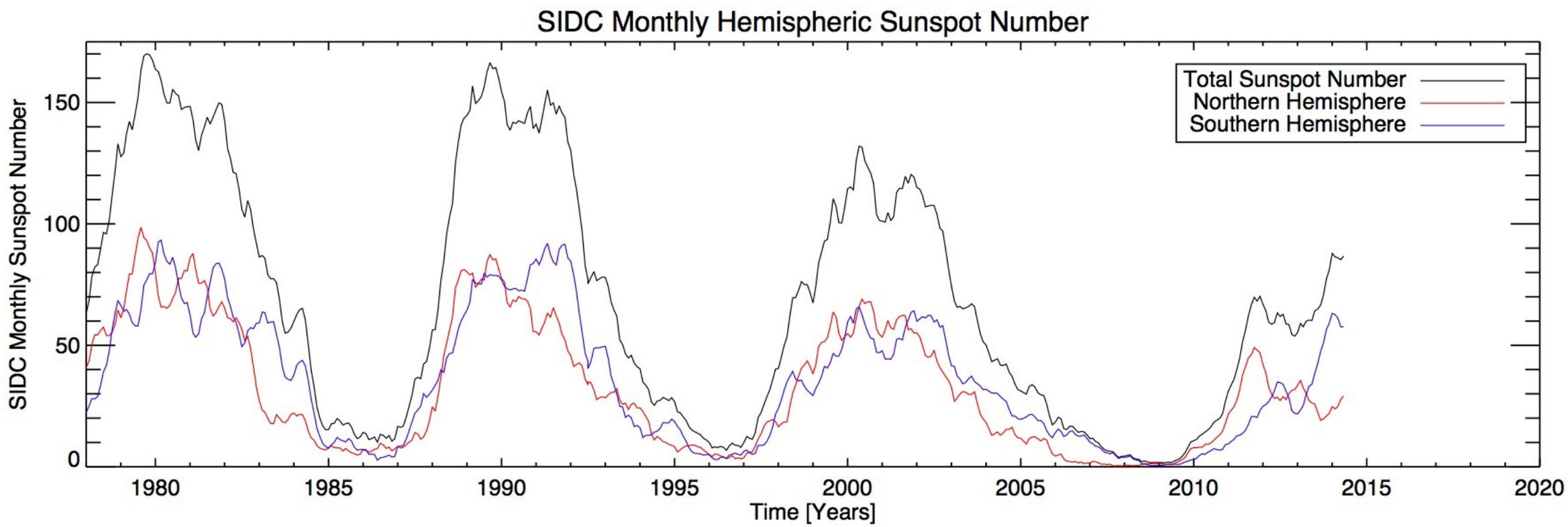

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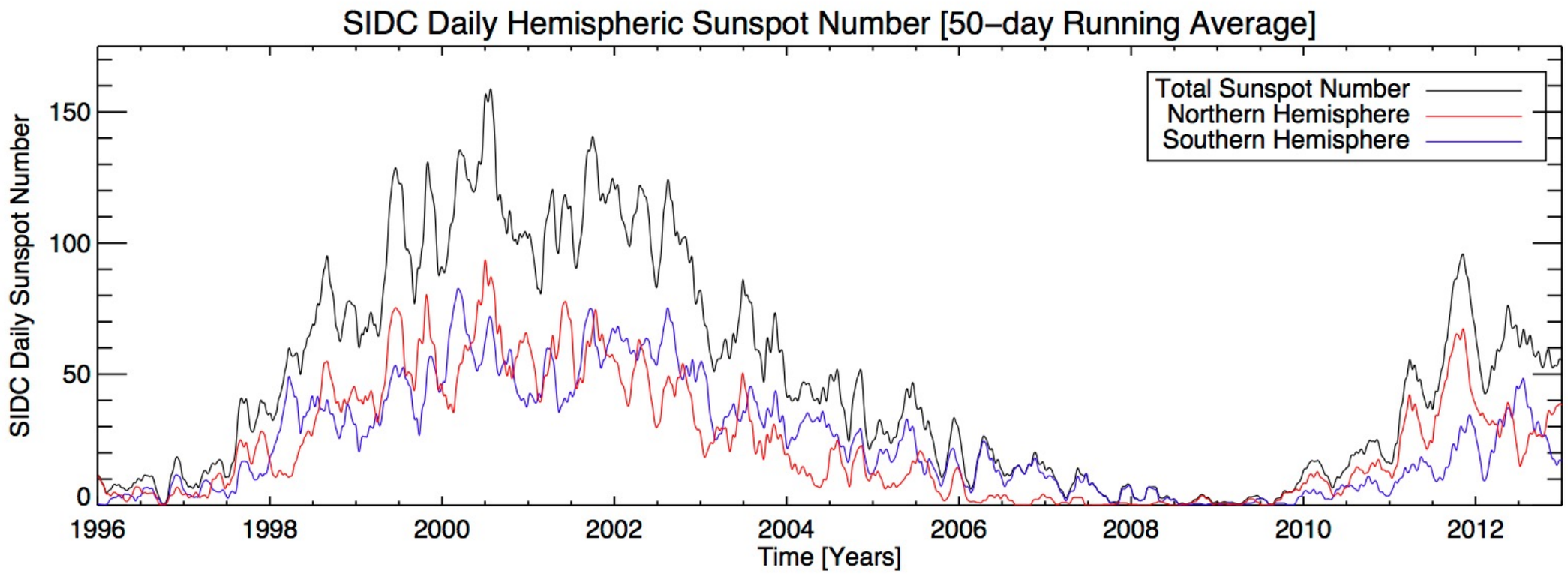

A question that motivates us…..

….what will it do….

…over coming months?

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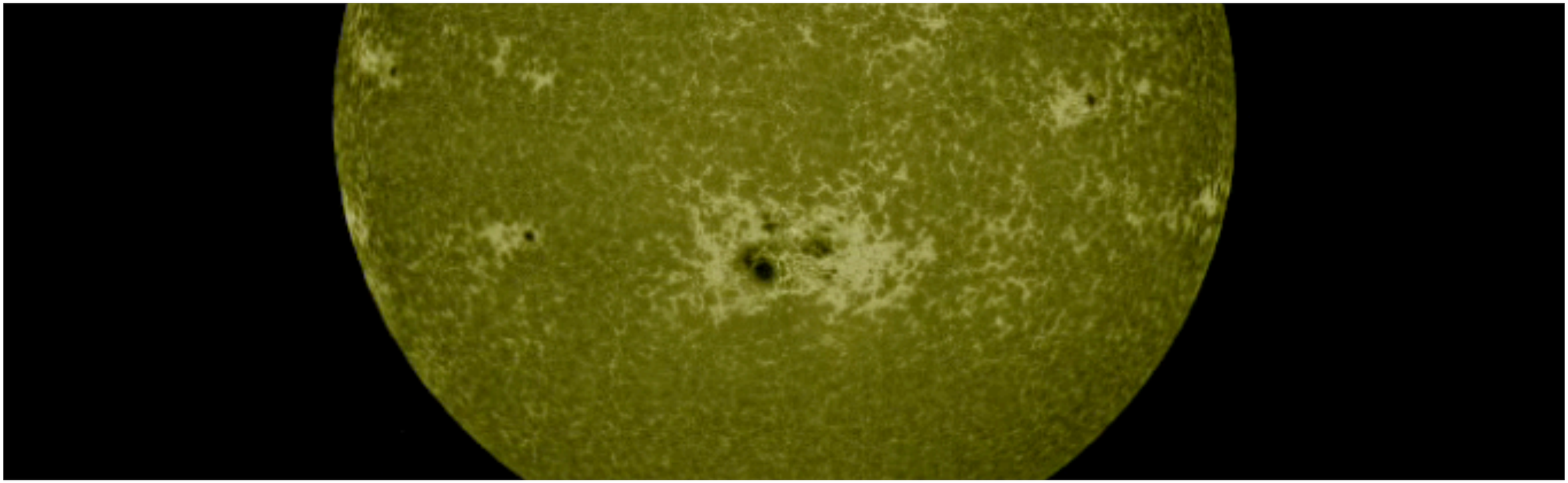


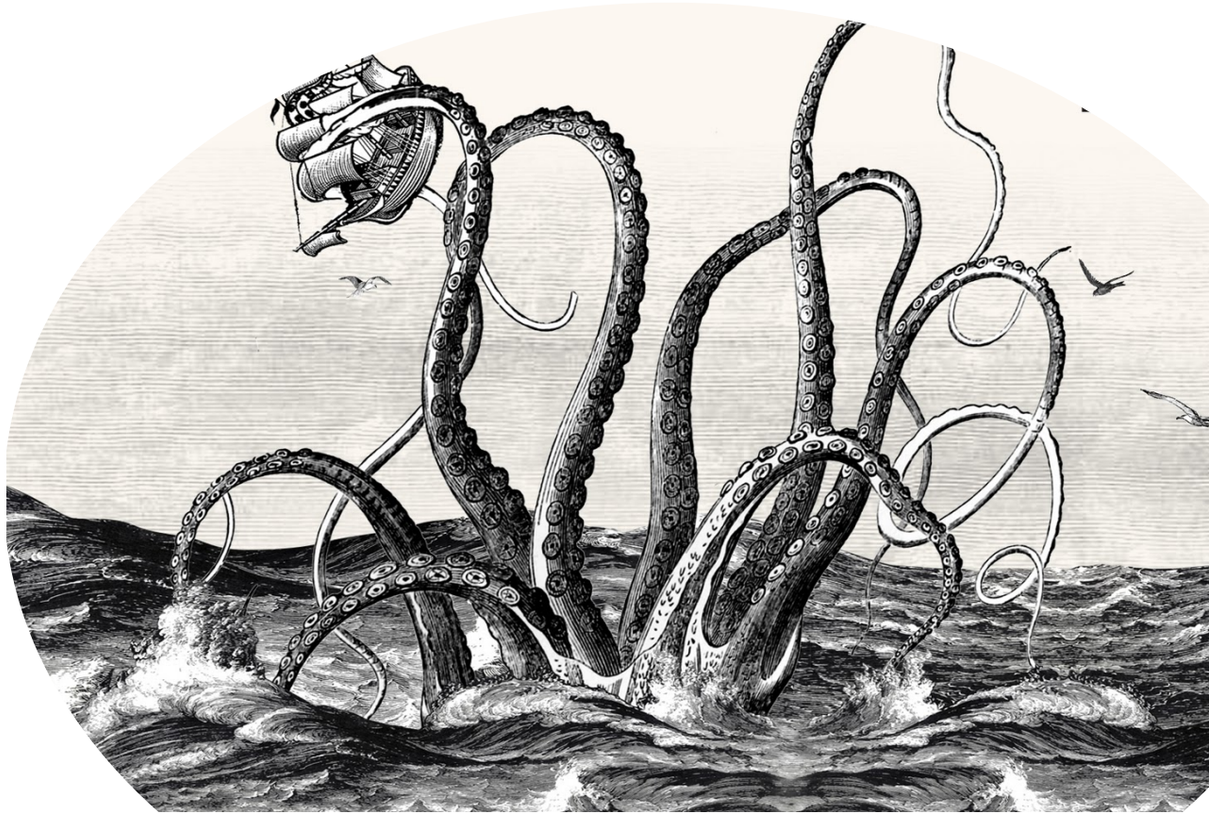
A question that motivates us…..

….what will it do….

…tomorrow?

The Grand [Central] Challenges

How does the Sun's internal magnetic machine produce the millennial, decadal, annual, and shorter-term solar variability?



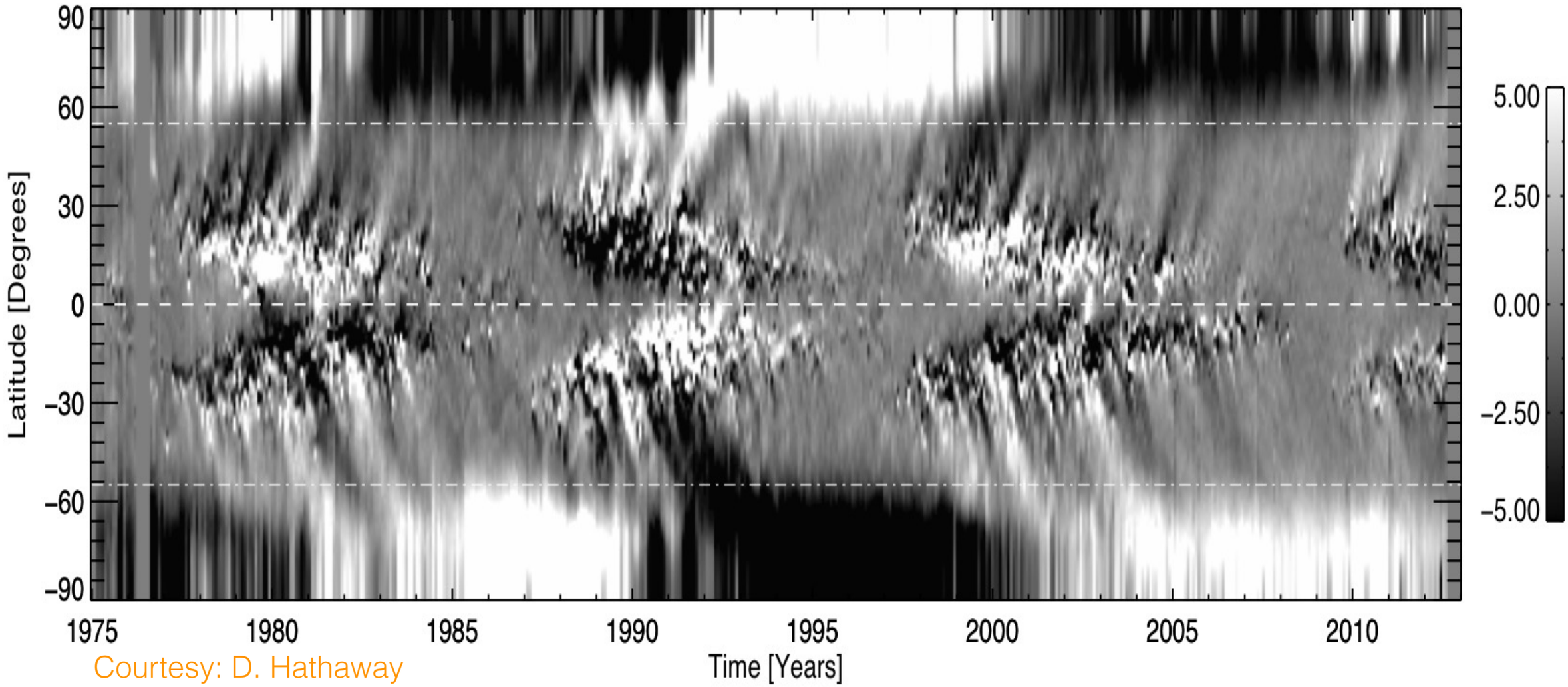
Can the processes at play be observed?

Do those observations permit a model where reliable hind- and fore- casts of activity over hours, days, weeks, months, years, decades, centuries (and millenia) to be developed?

How do we move forward?

Distracting/Misleading Butterflies

The key…



Courtesy: D. Hathaway

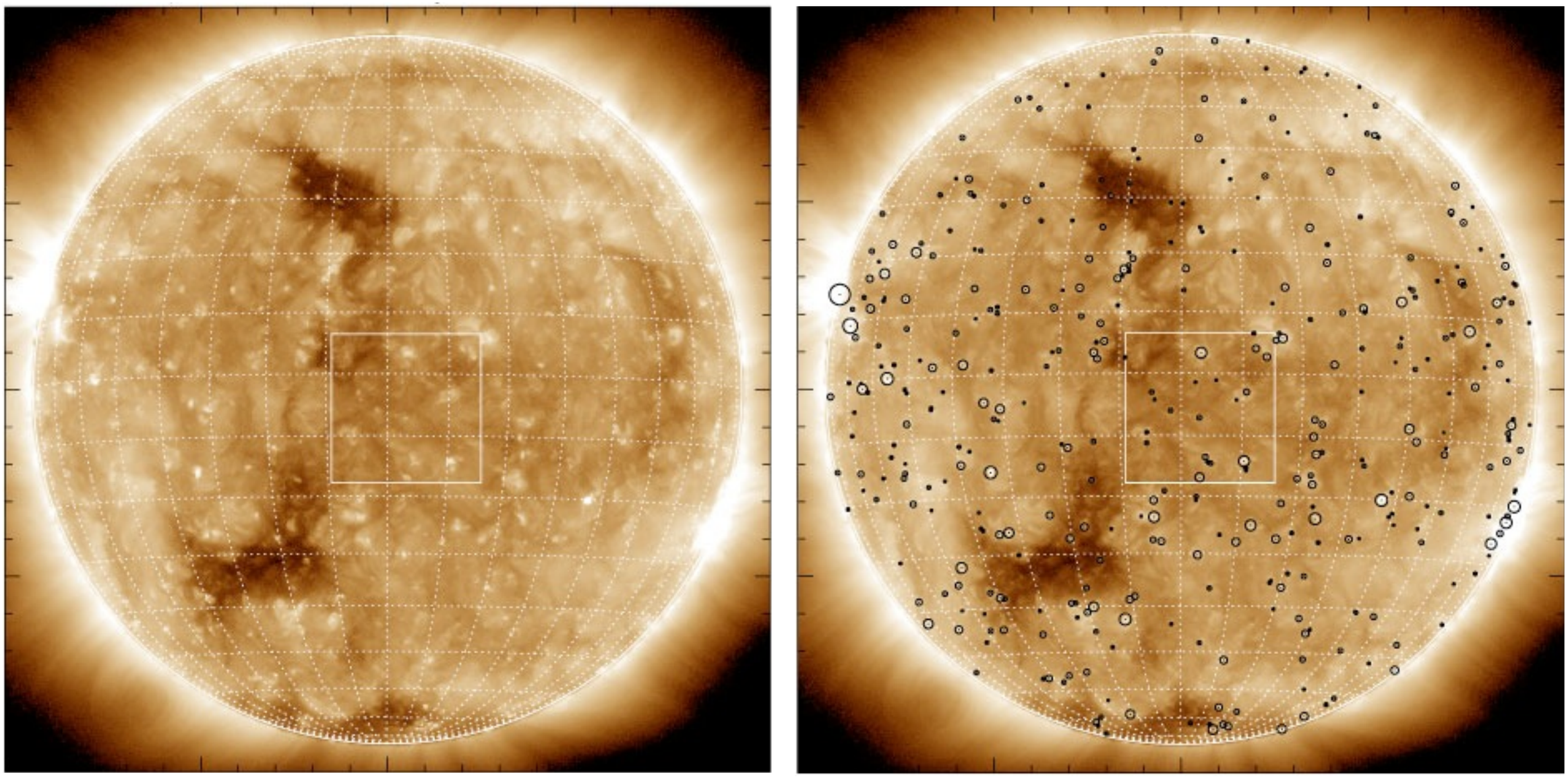
….lies in understanding the processes that govern solar magnetism

…unfortunately we only have the patterns that it produces….

…are those patterns complete and/or unique?

EUV BrightPoints

The coronal ever-present has a preferred location and formation (spatial) scale.



Magnetic Scales

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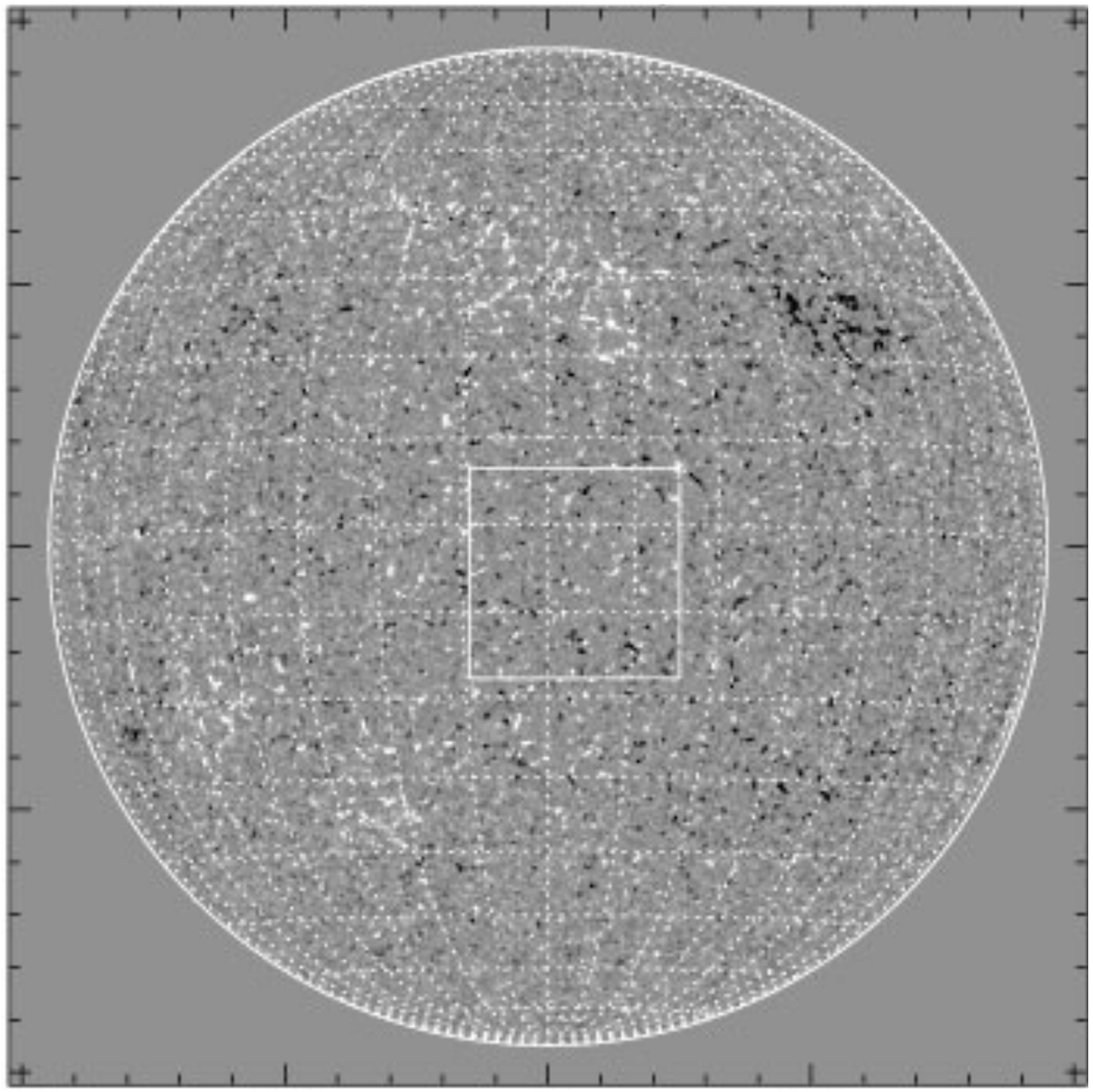
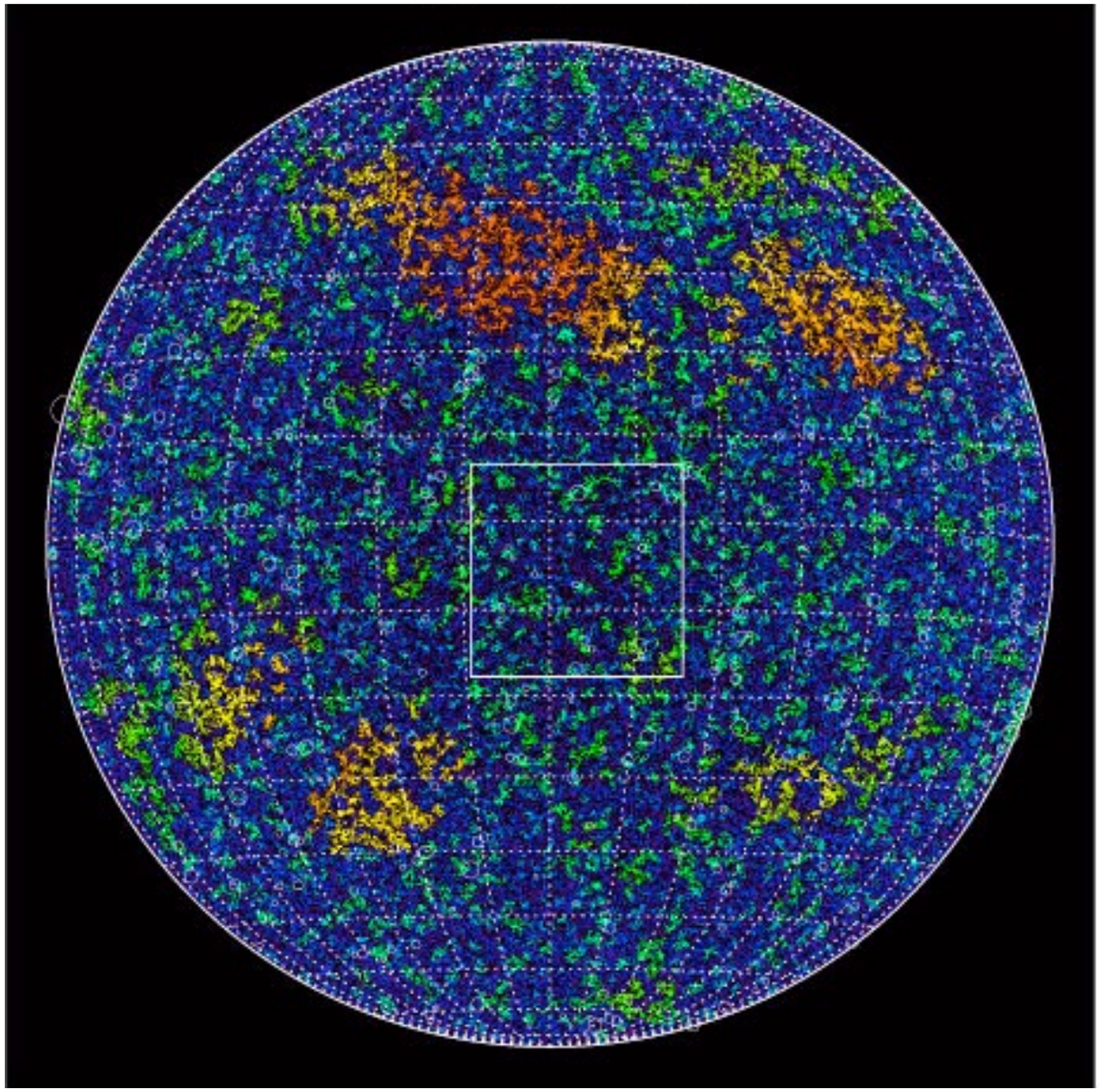
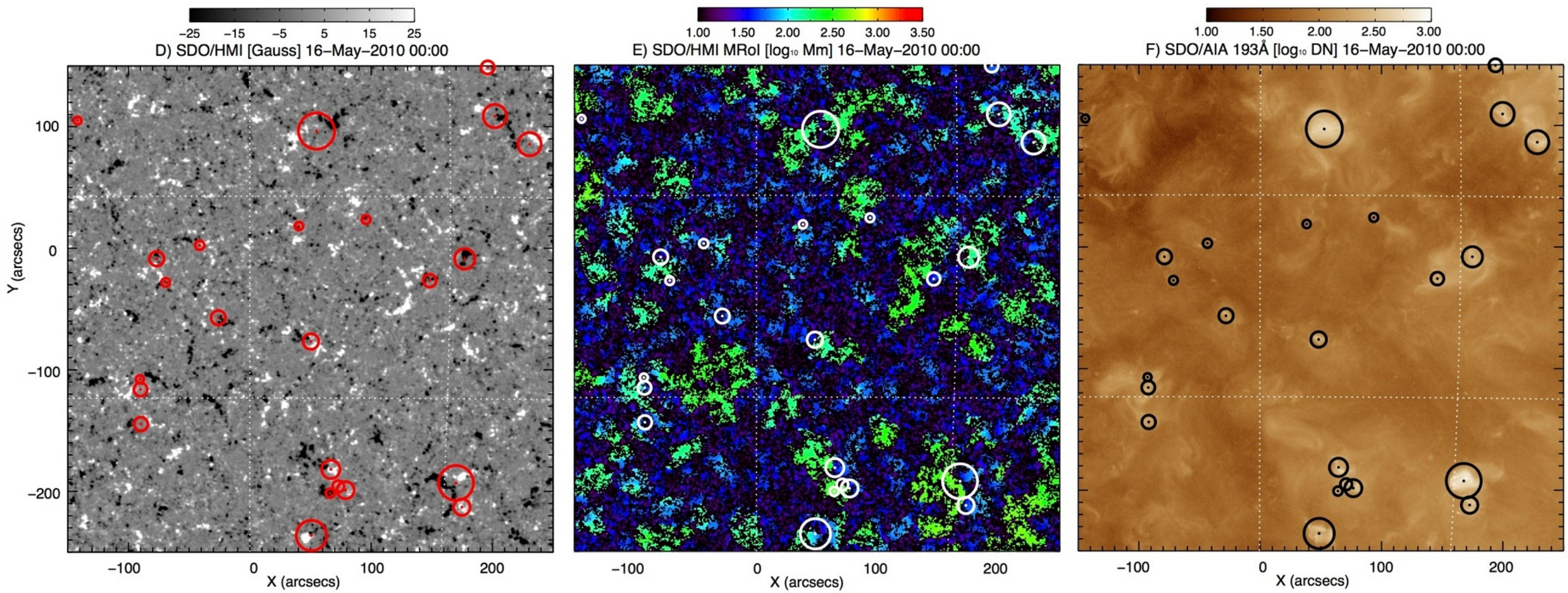




EUV BrightPoints & The “Giant” Scale?

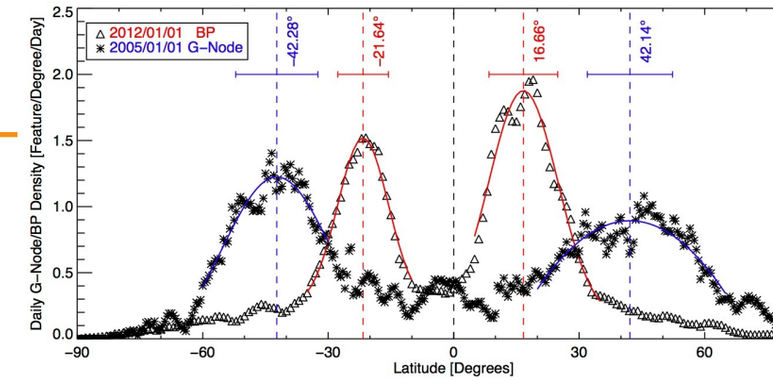
Brightpoints - NOT “simple dipole regions” formed at every supergranular vertex - they have a preferred location and spatial scale.

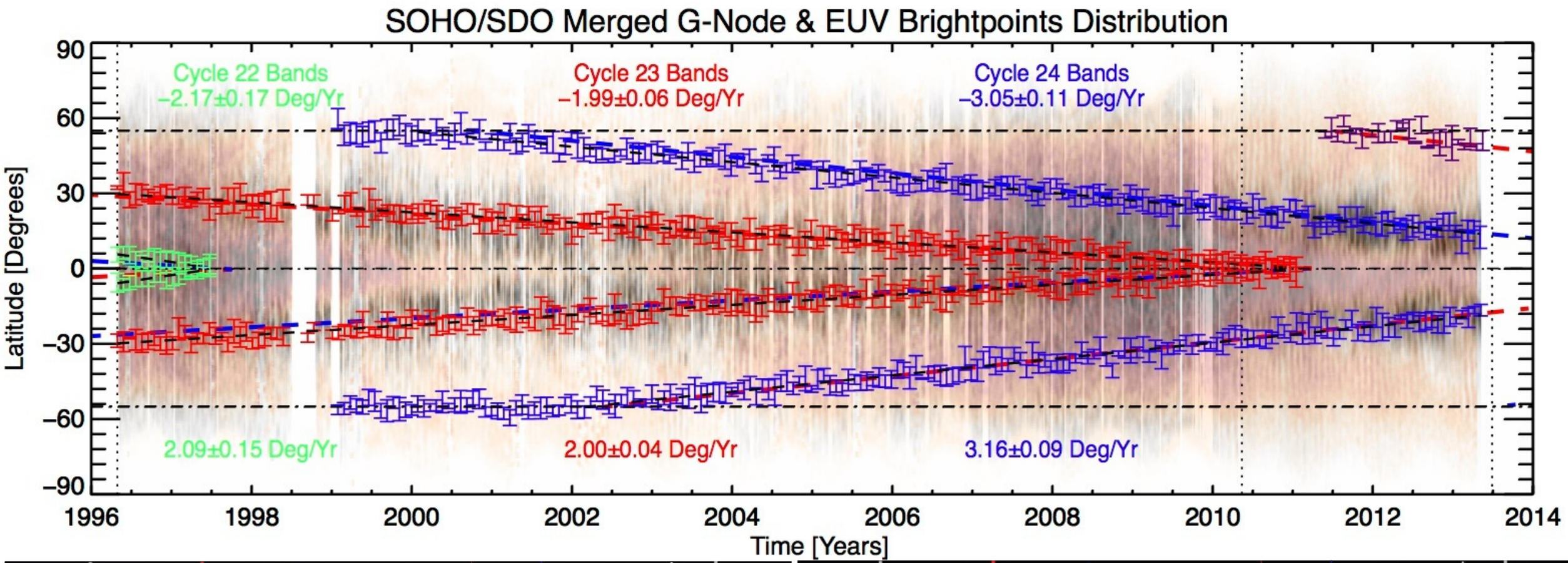


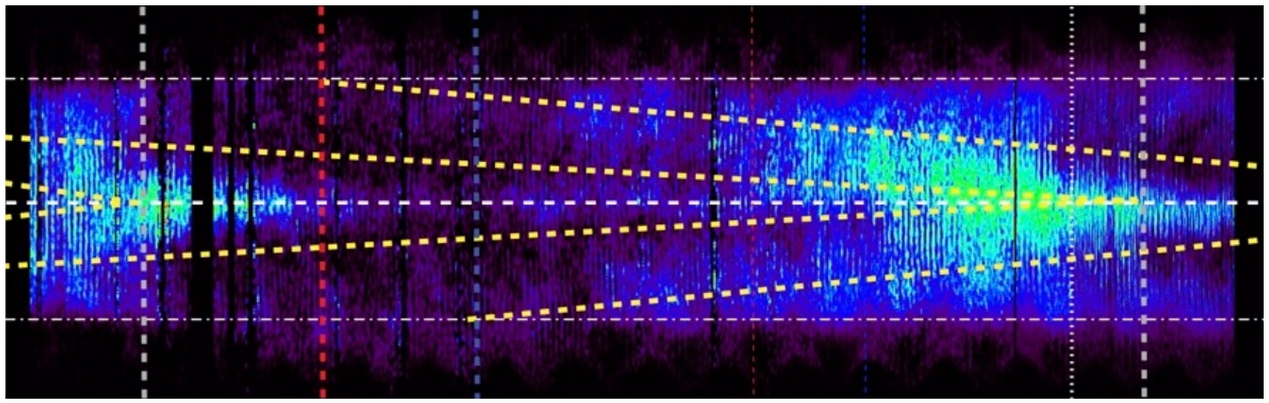
Form preferentially around a different kind of magnetic flux vertex - separated in scale by about 100-250Mm.

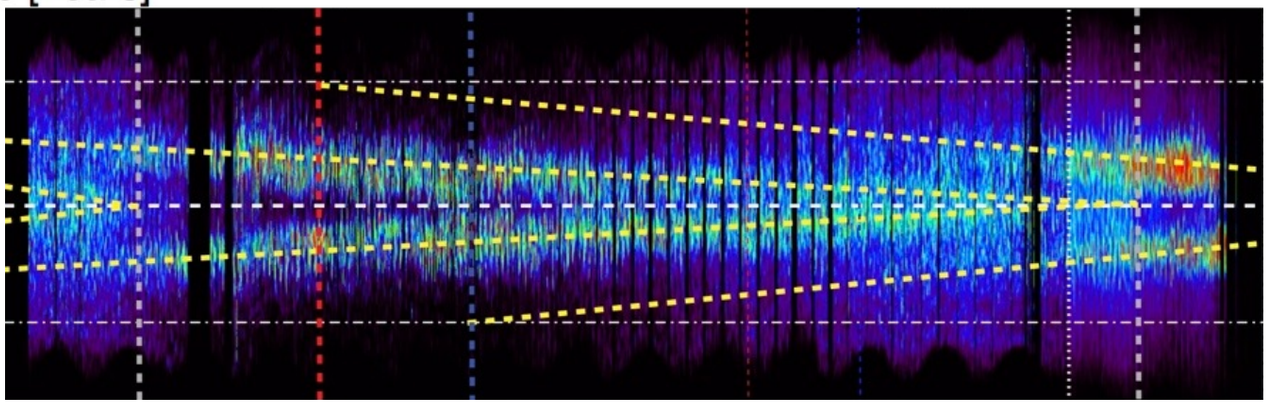
Band Identification

New diagnostics provide insight and add strong constraints on the origins and evolution of the solar (sunspot) cycle.









The Activity Band Extension : BrightPoints

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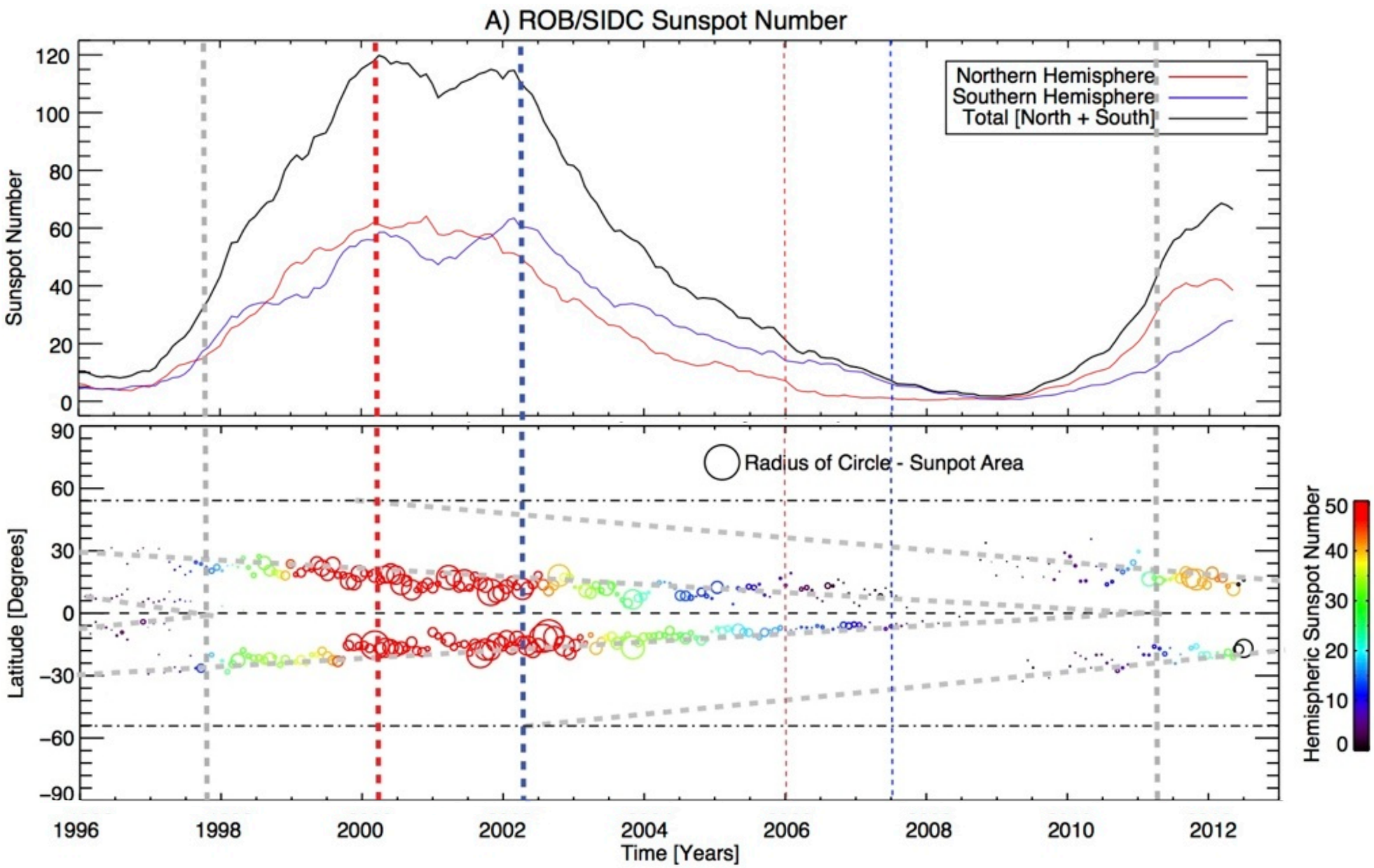
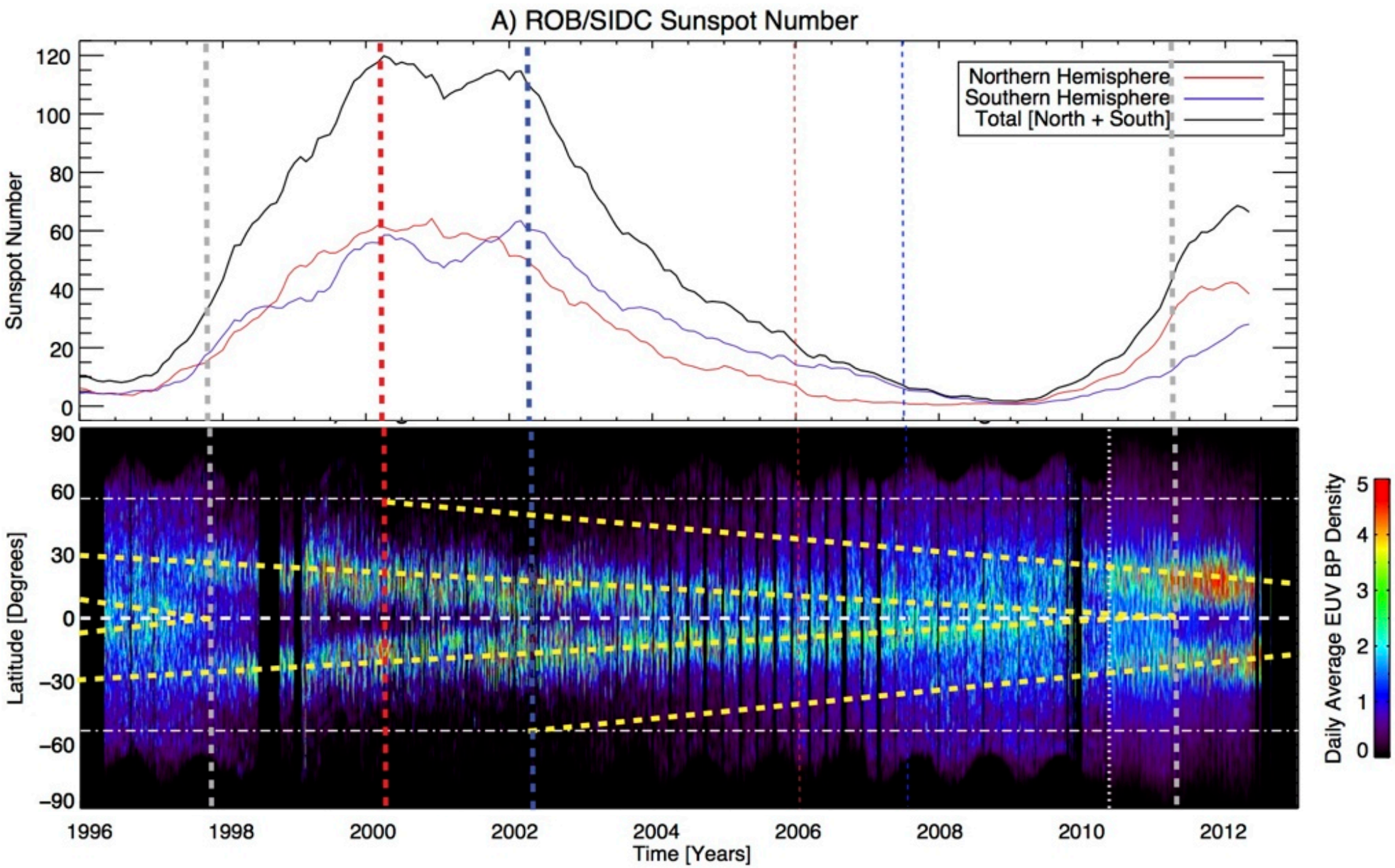


Comparing With (hemispheric) Sunspot Areas / Numbers

The Activity Band Extension : BrightPoints

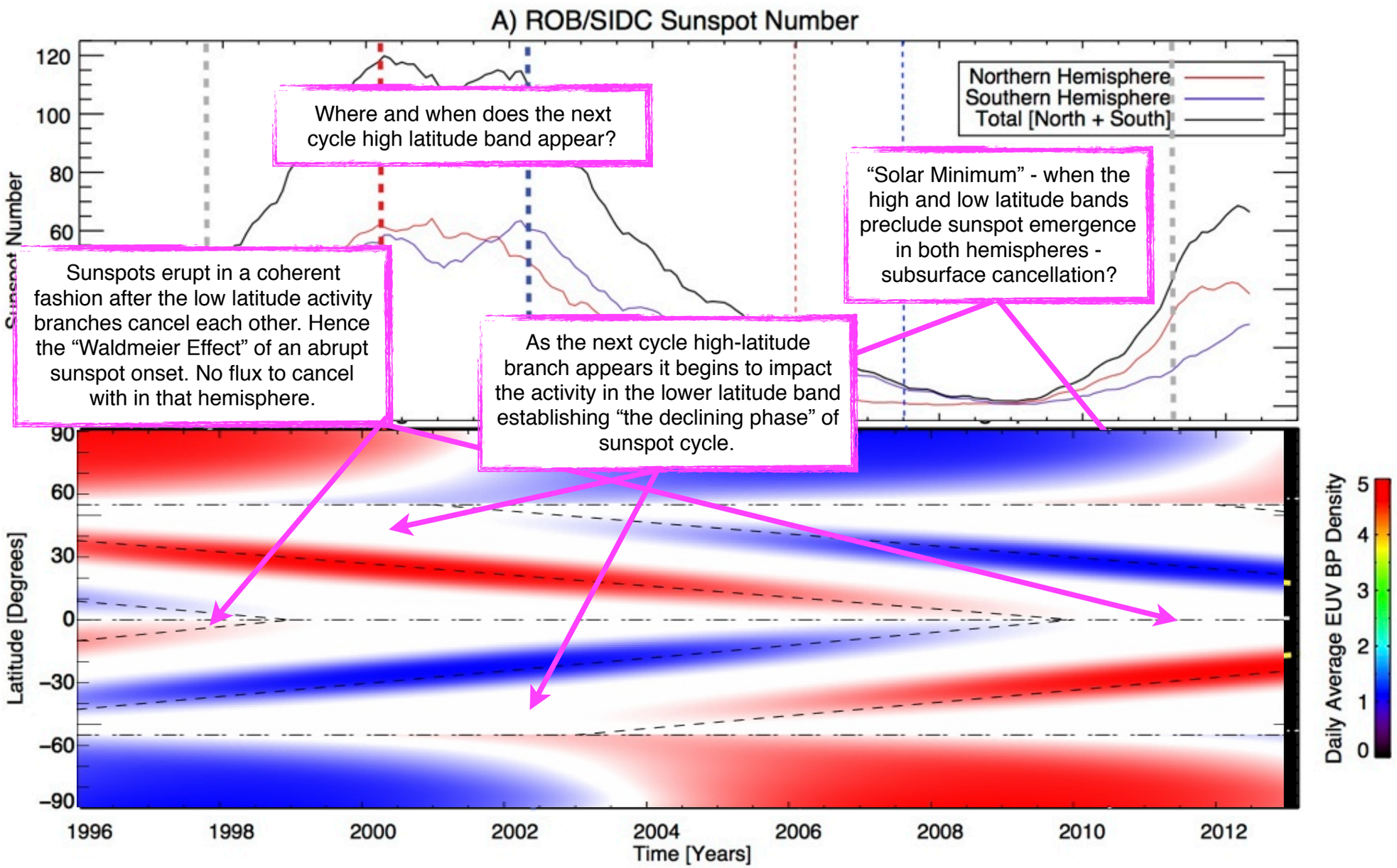
New diagnostics provide insight and add strong constraints on the origins and evolution of the solar (sunspot) cycle.



ID of small-scale magnetic features permit observation to 55° that **precede sunspot formation by >10yrs**

The Activity Band Extension : BrightPoints

New diagnostics provide insight and add strong constraints on the origins and evolution of the solar (sunspot) cycle.

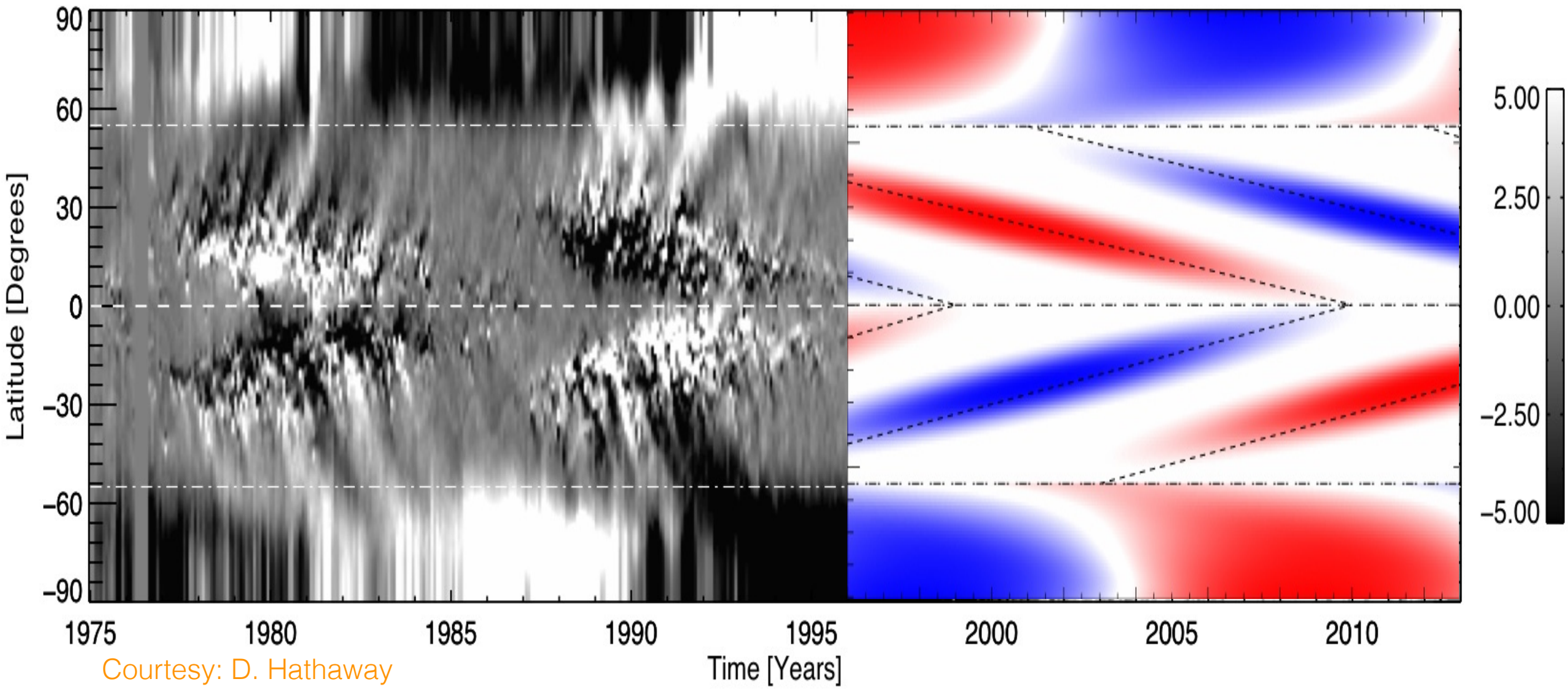


ID of small-scale magnetic features permit observation to 55° that **precede sunspot formation by >10yrs**

sunspot evolution and cycle governed by **overlap of oppositely-signed activity bands?**

Distracting/Misleading/Extending Butterflies

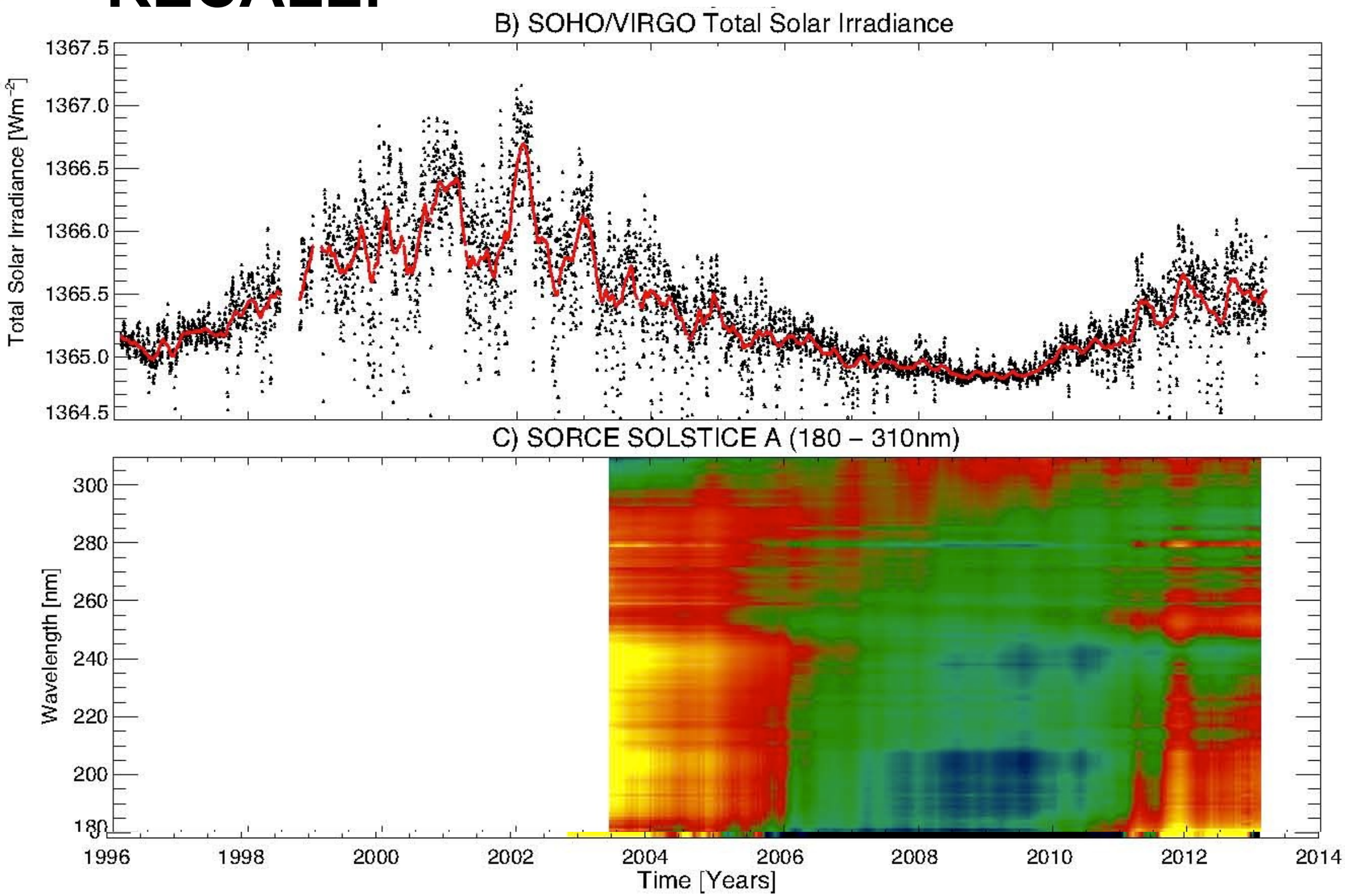
The activity bands on which sunspots form are “extended”!



Courtesy: D. Hathaway

But that Is Not All: Activity Band Instability

RECALL:



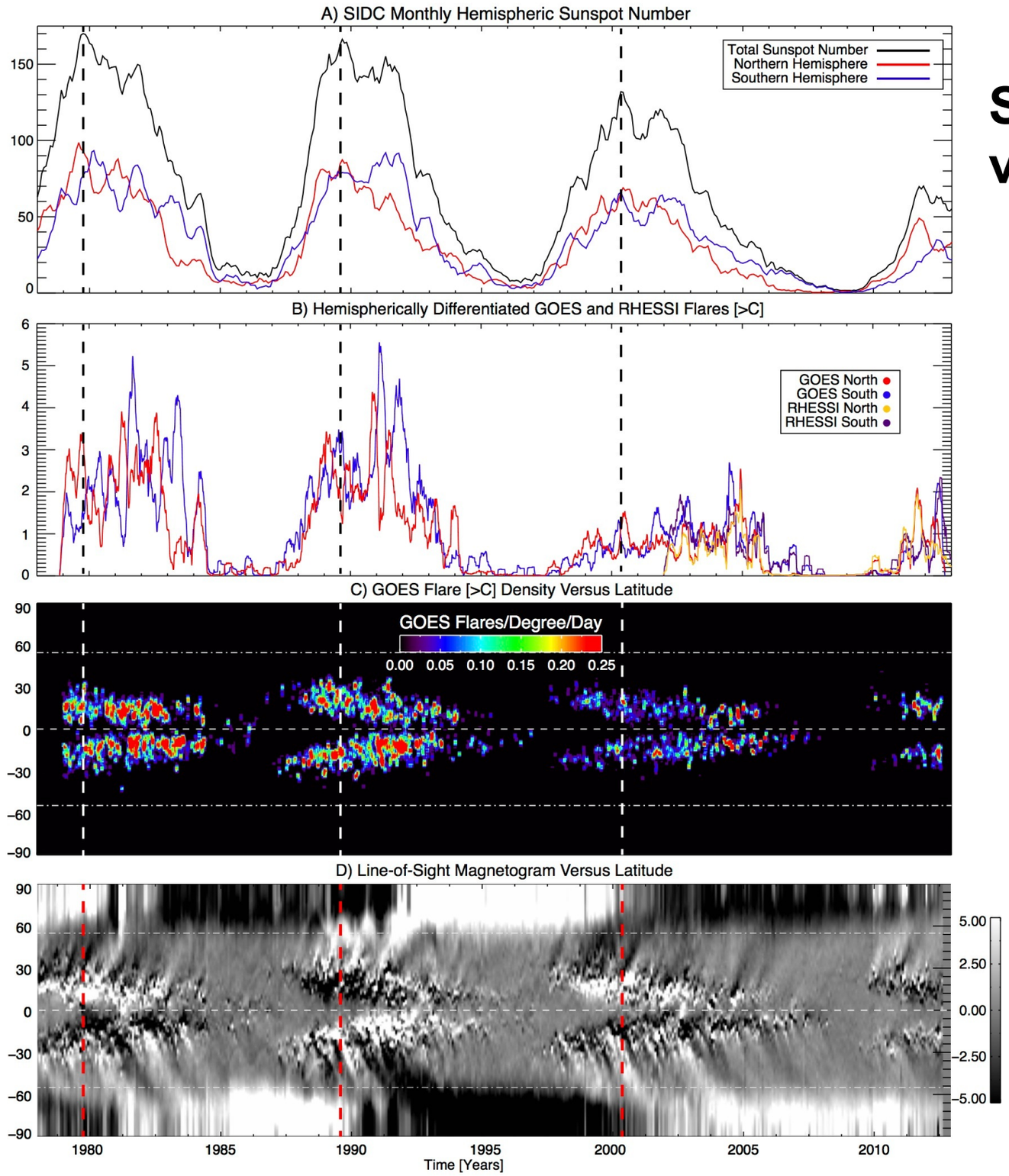
Activity Band Instability

hSSN

Flares >"C"

Flare "PDF"

B_{LOS}



Some process is modulating variability on those bands….

NOTE:
- Overall Decline in Magnetism
- Overall Decline in SSN
- Overall Decline in Flaring

Is significant contributor to "multi-peaked" SSN.

Hemispheric Phase Variance

$Flare_{MAX}$ later than SSN_{MAX}

Follows by >1year

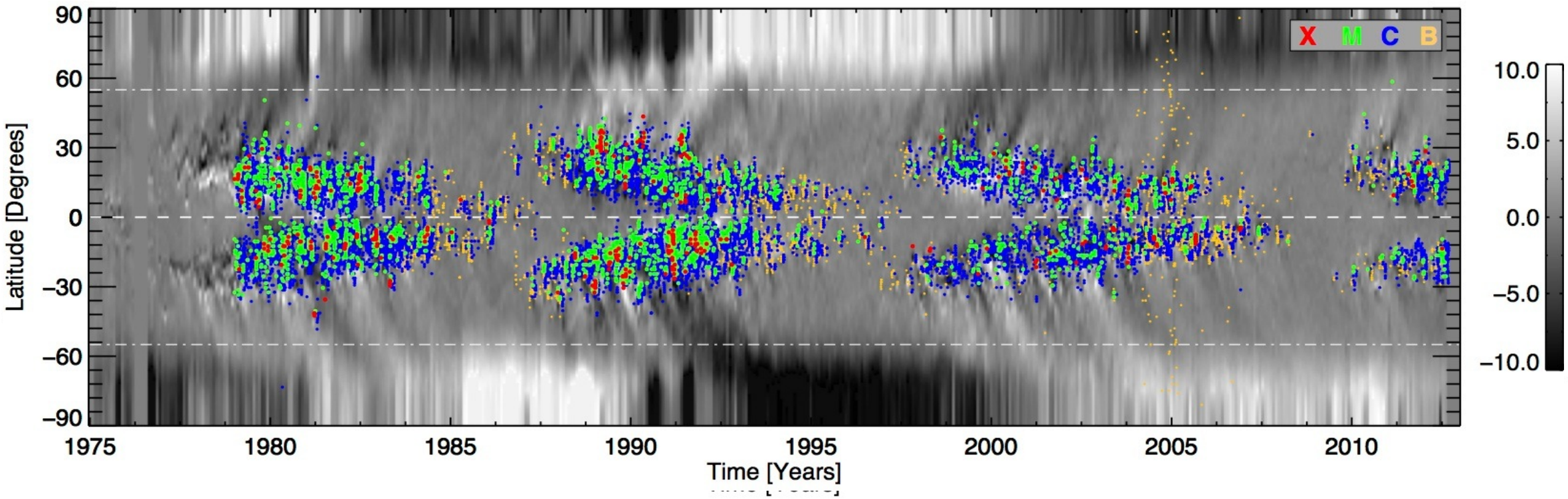
The "Gnevyshev Gap"

Produces Clear Flare Clustering

In Latitude AND Time

Activity Band Instability

McIntosh et al. (2014b)

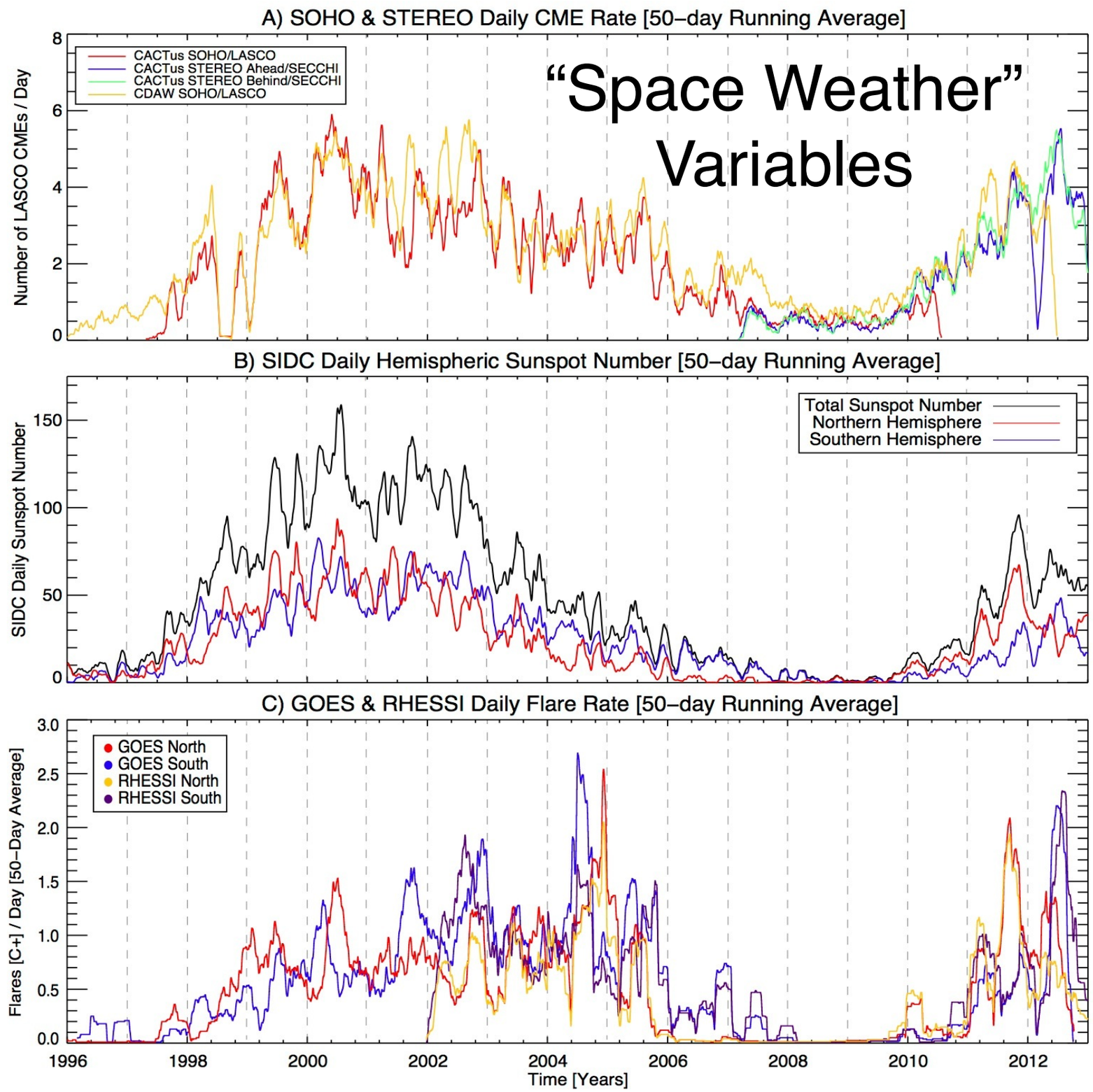


Low energy flares (<C) occur can at ANY phase of the sunspot cycle.
Related to latitudinal progression of sunspots, possible clustering.

Higher energy flares (~M) "cluster" in latitude and time.

Highest energy flares (~X) clearly "cluster"
(flares tend to appear on the periphery of the "butterfly")

Activity Band Instability & Space Weather

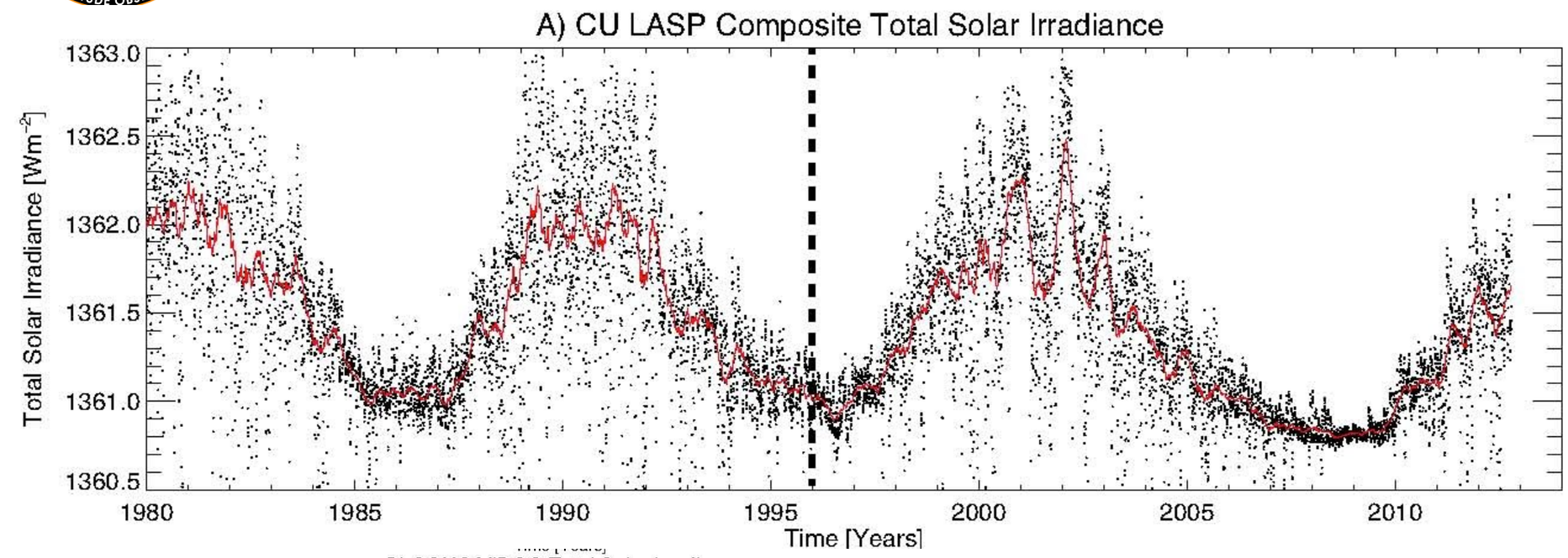


Coronal Mass Ejection
"CMEs"
Rate ~100% Increase

(h)SSN
Rate ~50-100% Increase

Flares
Rate >100% Increase

Activity Band Instability & Solar TSI/SSI



"Radiation"

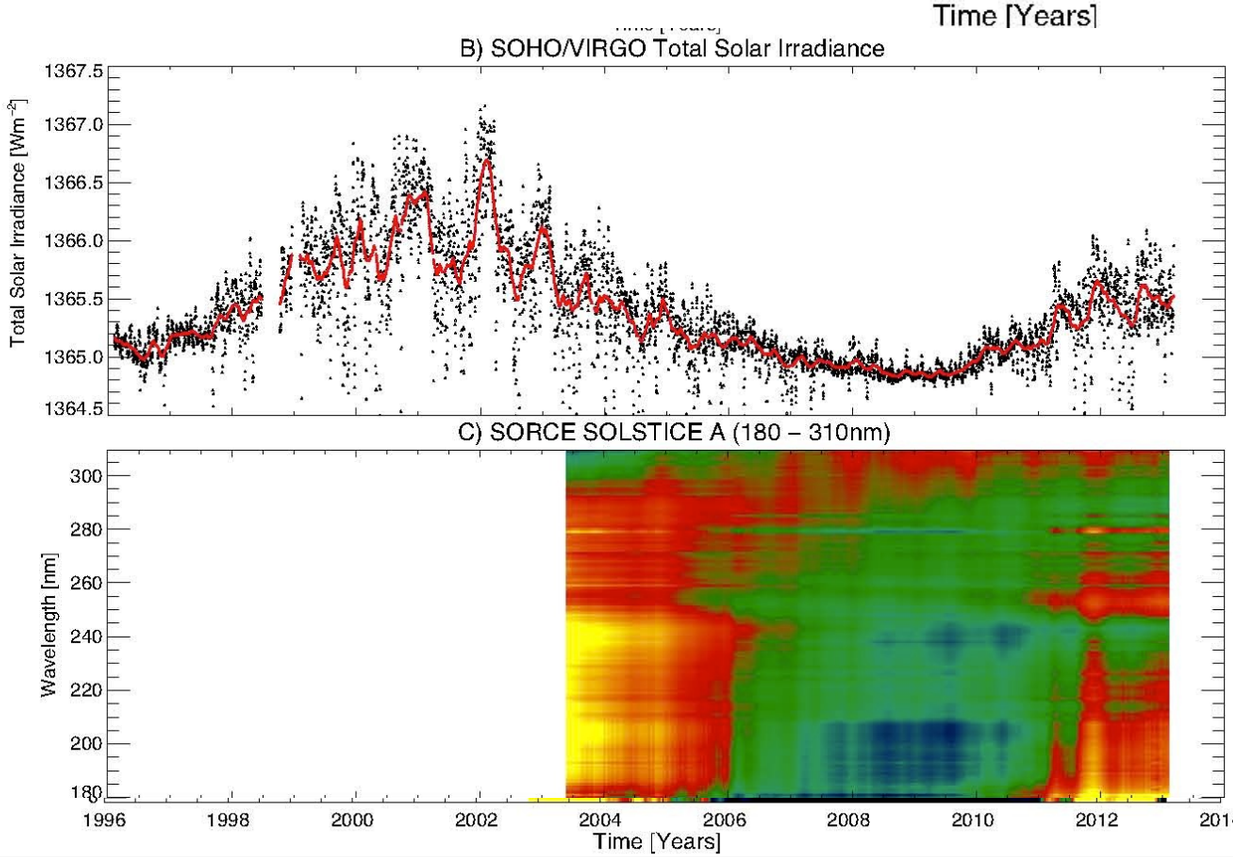
TSI ~1Wm^{-2}yr^{-1}

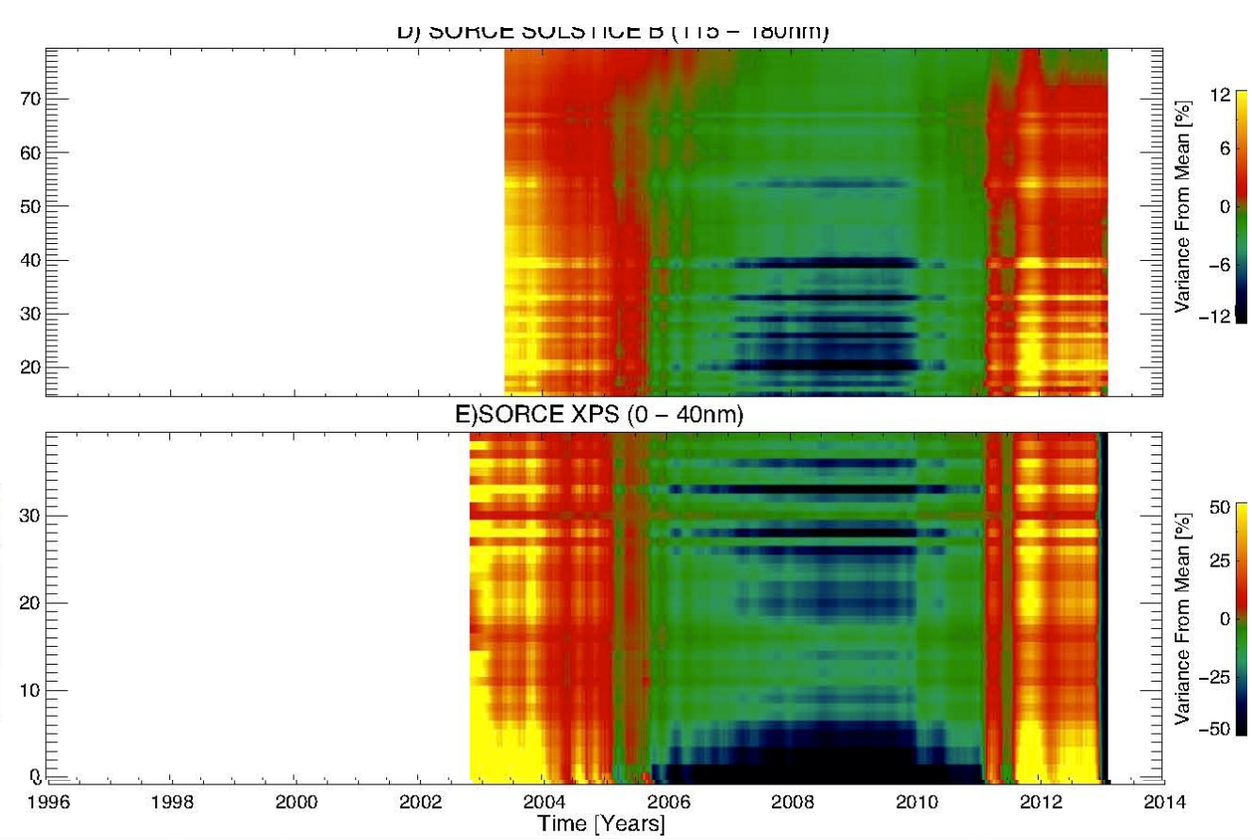
SSI_{UV} ±5%

SSI_{EUV} ±15%

SSI_{XR} ±75%

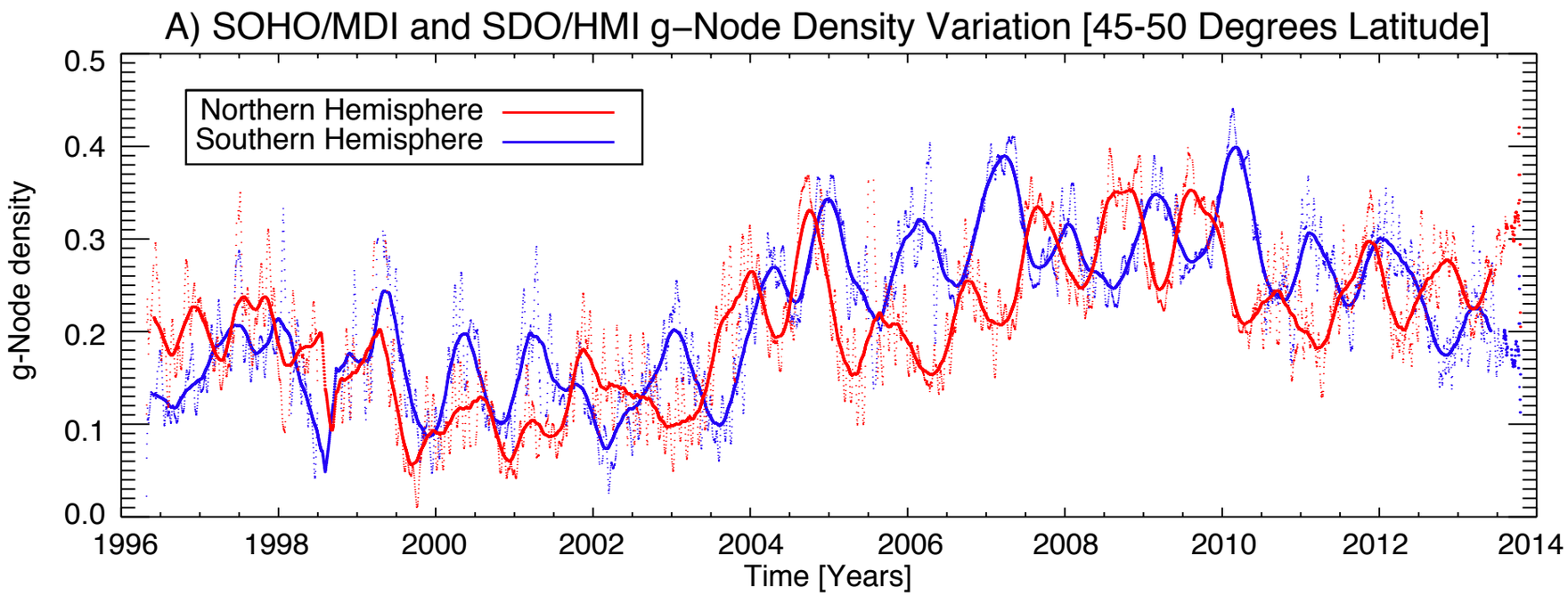
$SSI_{Opt/IR}$ ±?



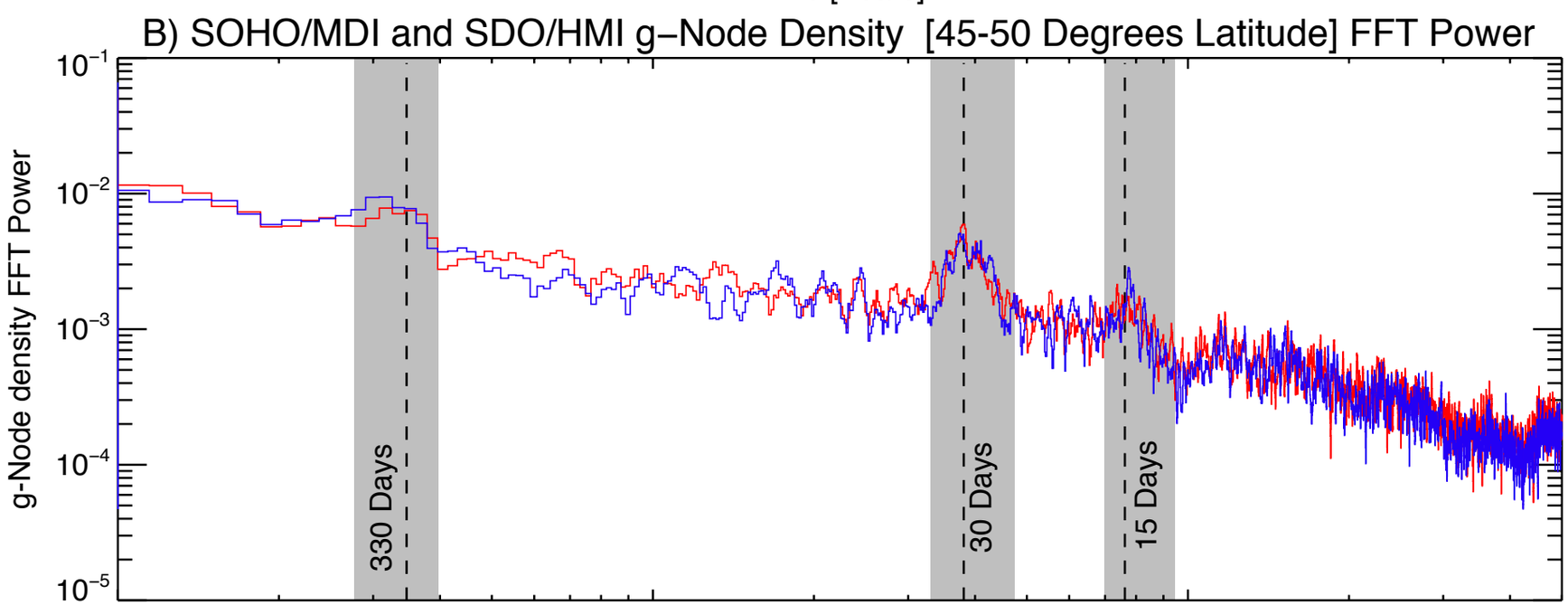


Activity Band Instability

Observations reveal (very) strong surges in solar magnetism
Effect storm production, radiative, and particulate output.

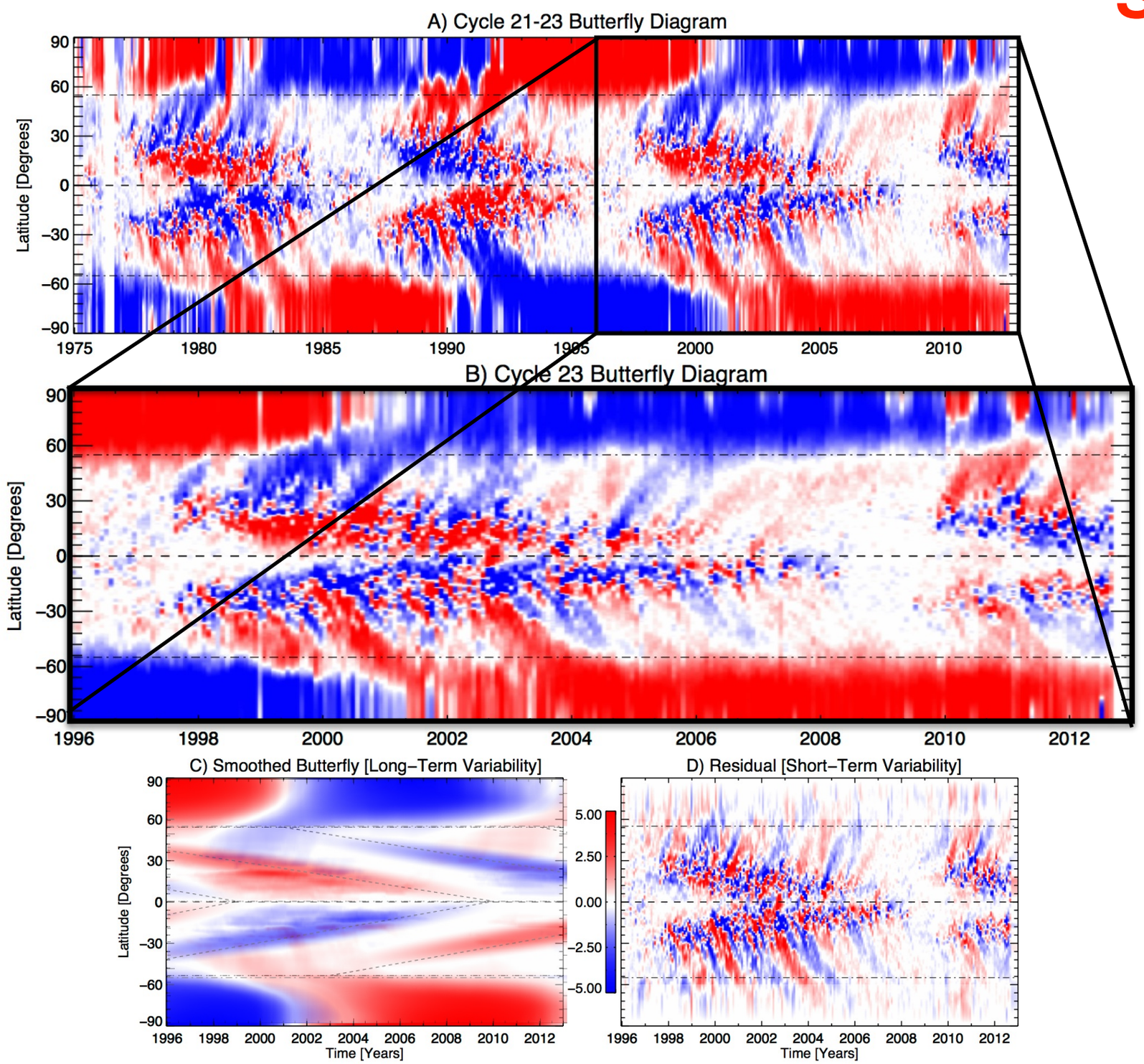


g-node/BP monitoring (in each hemisphere) permit assessment of surge phase…..



Understanding: Are there eruptive energy/momentum transport phenomena on the Earth's "activity bands" that we can learn from?

Activity Band Instability: Cause?



Surges of Magnetism

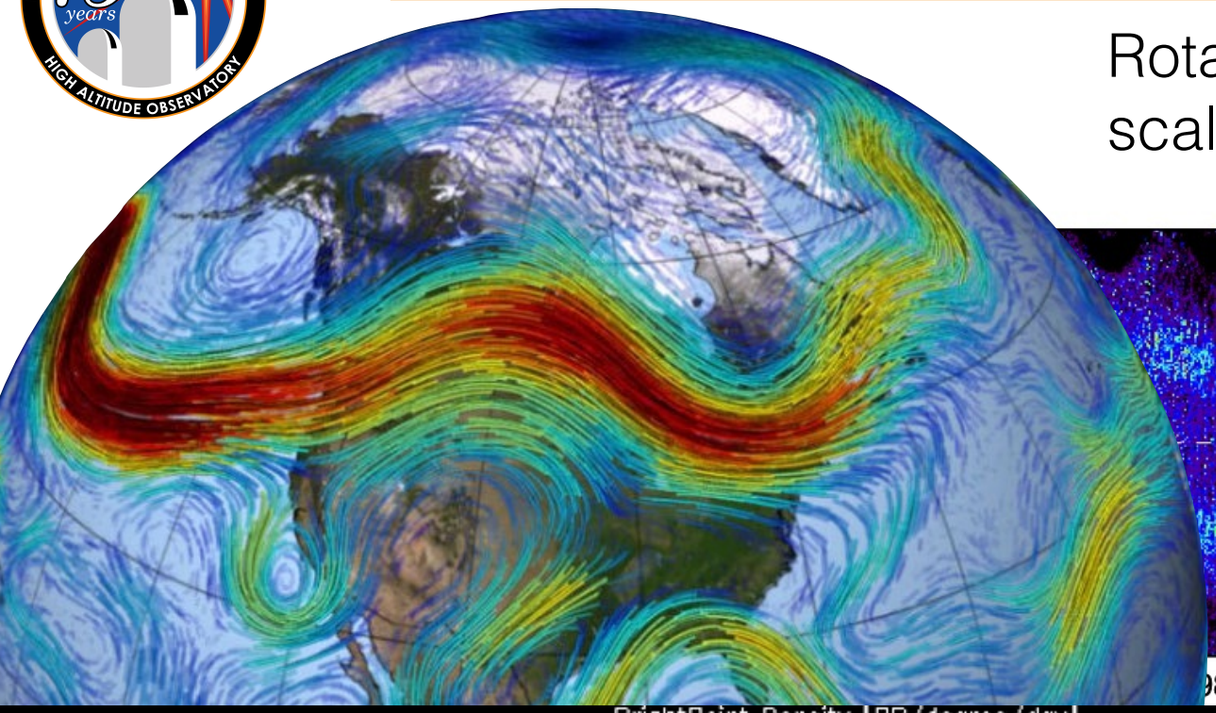
….apparent poleward motion of magnetic flux from the activity bands….

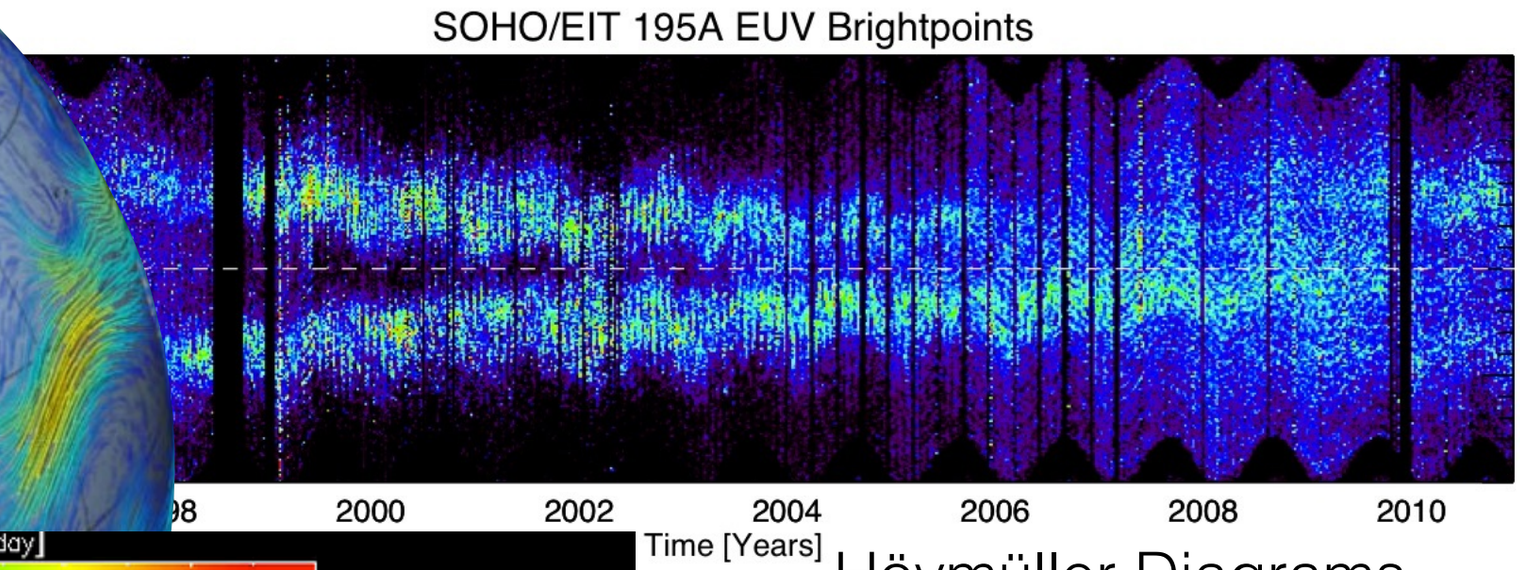
….apparent poleward motion is likely what happens when you feed the Sun's surface meridional circulation…..only a result of flux surge?

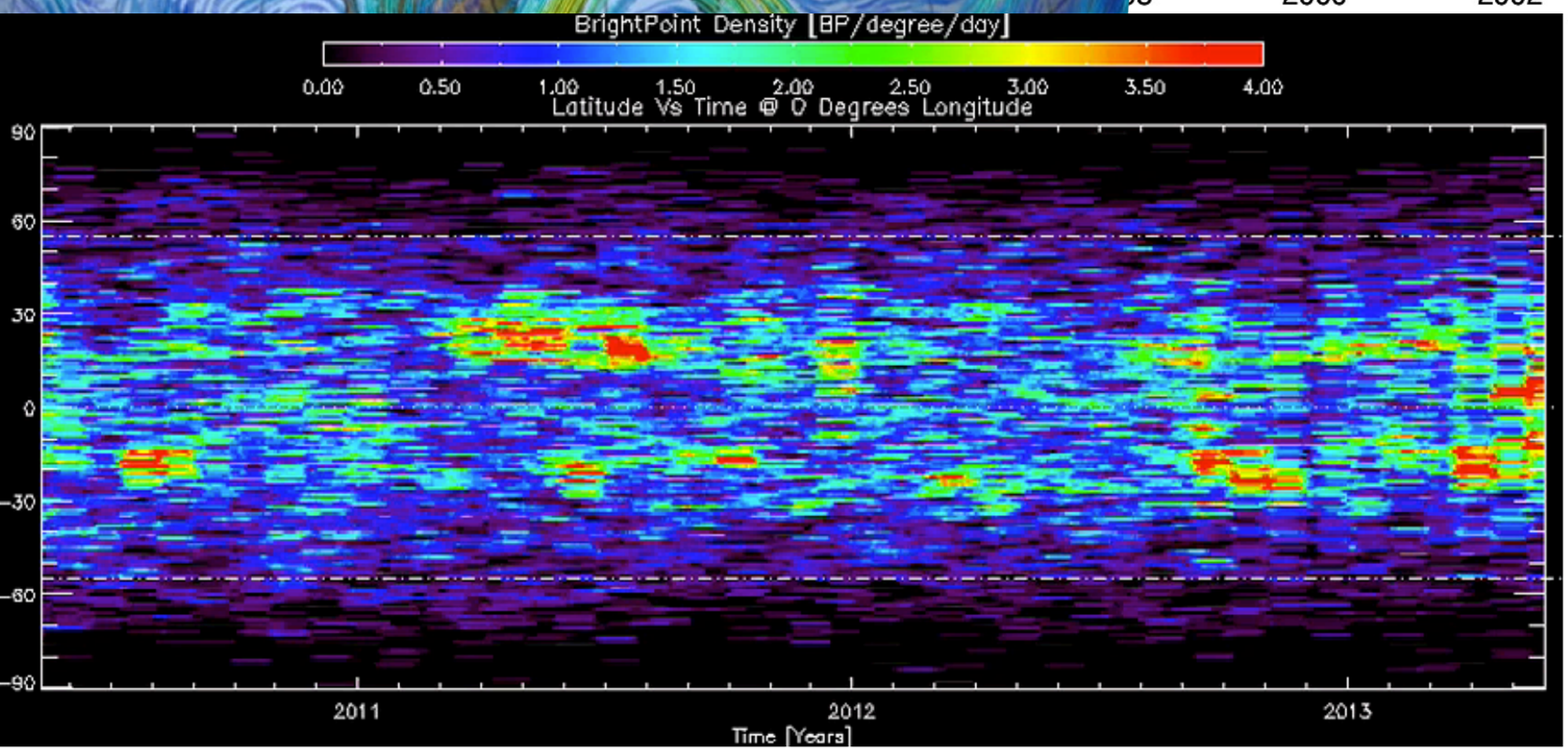
…..effect of global internal rotational dynamics rather than of the dynamo action itself?

Activity Band Instability: Driver?

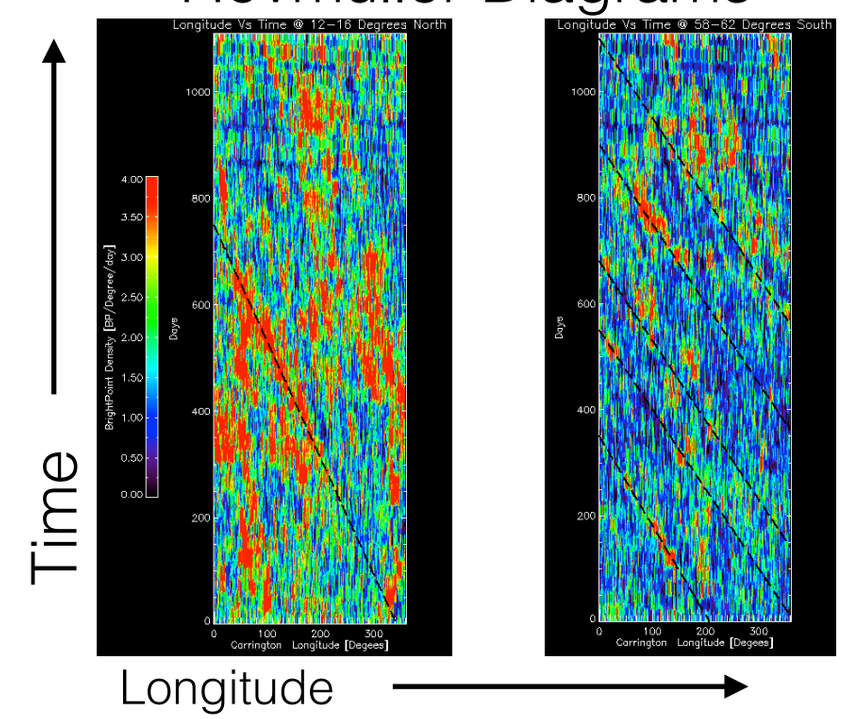
Rotating atmospheres drive (meandering) global-scale motions like Rossby waves







Hövmüller Diagrams



Sun-Planetary Analogy - Need to Study Global Magnetism/Environment

Take Home

1. **Sunspot cycle appears to be a consequence of the interaction of latitudinally and temporally overlapping activity bands of the 22-year magnetic activity cycle.** An "interference pattern" of mutually canceling magnetic systems?

2. System seems to be **driven by the rotation of the radiative zone** and global-scale resulting (magneto-)hydrodynamics.
   - High latitude evolution seems to play a critical role in timekeeping and evolution of the system?

3. **Strong variability** (**of similar magnitude to cycle) of the activity bands** on timescales much shorter (~11 months) than the solar cycle:
   - Drives STRONG modulation in radiative, particulate and eruptive solar output
   - We tend to ignore it, but shouldn't!

….. this work yields potential insight into complex active region formation, grand minima entry and exit, and extreme event occurrence ……

★ **NEED to observe solar magnetism from all perspectives to capture the global scale evolution of the magnetic field. Need new observing strategy and platforms for task.**

★ **What is the solar dynamo?** Clearly we are **missing/overlooking/ignoring some vital observational clues** that can help to constrain the problem and drive a break through in understanding of our star (and others).

Are our models of the Sun's interior really "up to snuff". If not, what do we do?