Contributions of VIRGO to our understanding of TSI Variability

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Outline

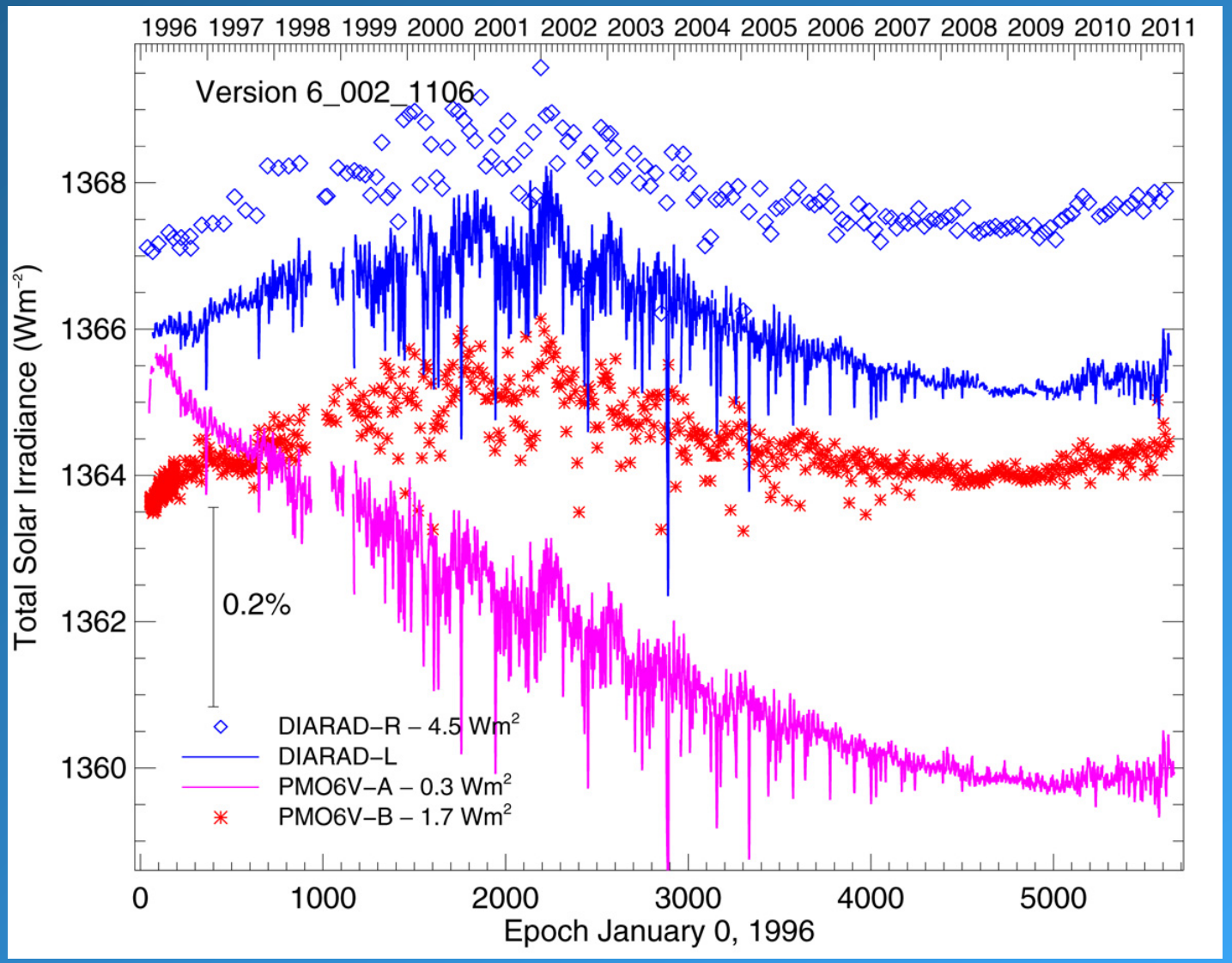
- Some historical remarks on the VIRGO Experiment
  - Science objectives: total and spectral irrandiance, helioseismology
  - Involvement of Douglas as CoI
  - First results
- Total solar irradiance variability during Cycle 23
  - Analysis of VIRGO Radiometry
  - Importance of the two different types of radiometers
  - How significant is the large difference between the minima in 1996 and 2009
- Discussion of TSI variability during the last 3 cycles
  - Comparison of the three existing composites
  - Comparison with models
  - Possible mechanism explaining the bahaviour

Historical Remarks

- The planning of the VIRGO experiment started in the late 1980ties and I had an excellent science team of theoreticians and instrumentalists together with a technical team with innovative ideas to realize the experiment.
- The instrument development was guided by the science objectives defined and the involvement of the theoreticians was important
- The H/W institutes finally did an excellent job in building the instruments and the control electronics together with the data acquisition– which is still fully operational after more than 15 years in space
- The science objective are best defined by the name of experiment: Variability of irradiance and gravity oscillations
- The first results – presented at the IAU Symposium in Nice - showed that all instruments performed as expected or even better although we did not yet understand fully the detailed behaviour of the instruments. Also very interesting scientific results were presented –mainly on helioseismology and related issues – TSI was not yet ready.

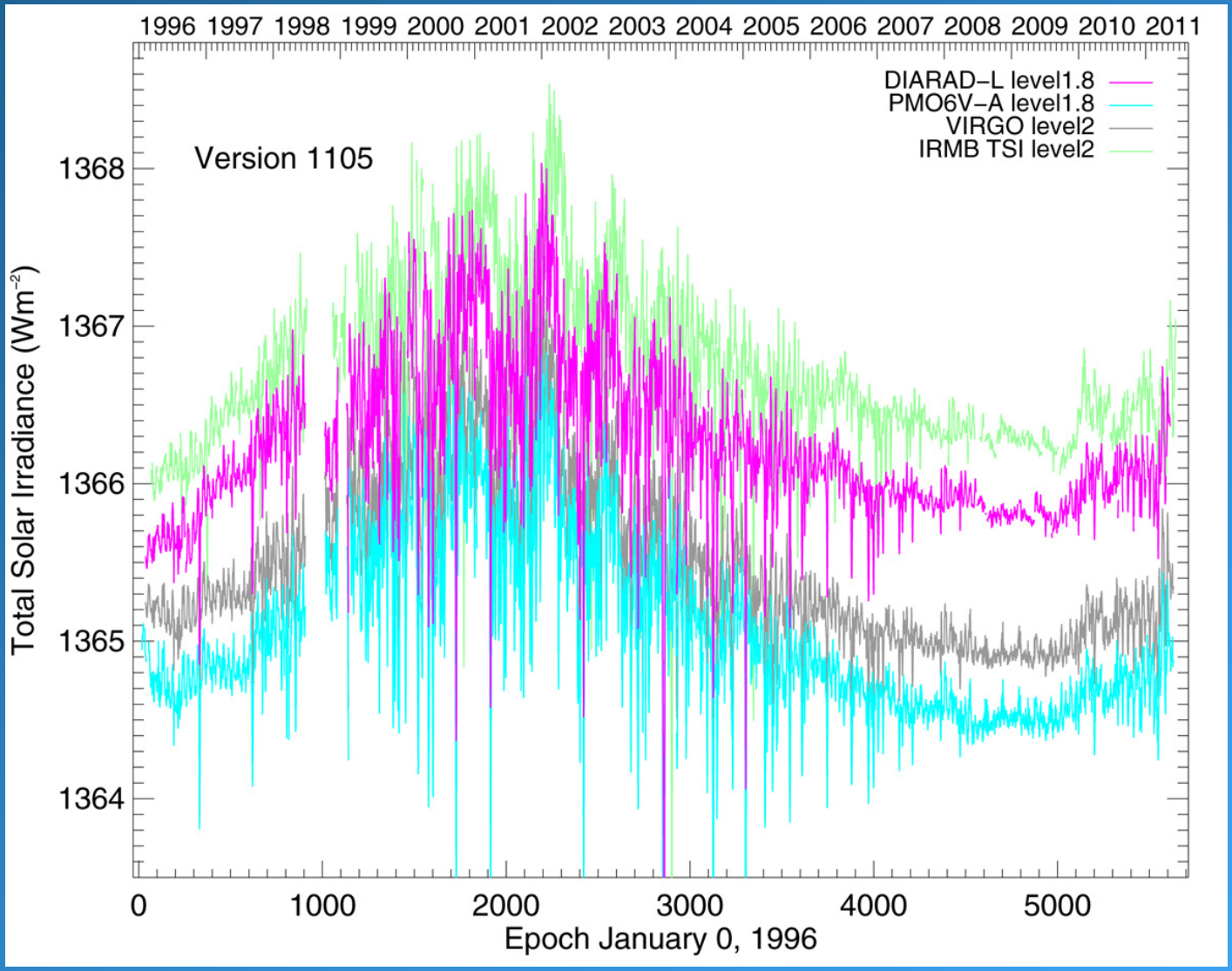
VIRGO Radiometry

The level 1 data show quite a different behaviour of the two types of radiometers



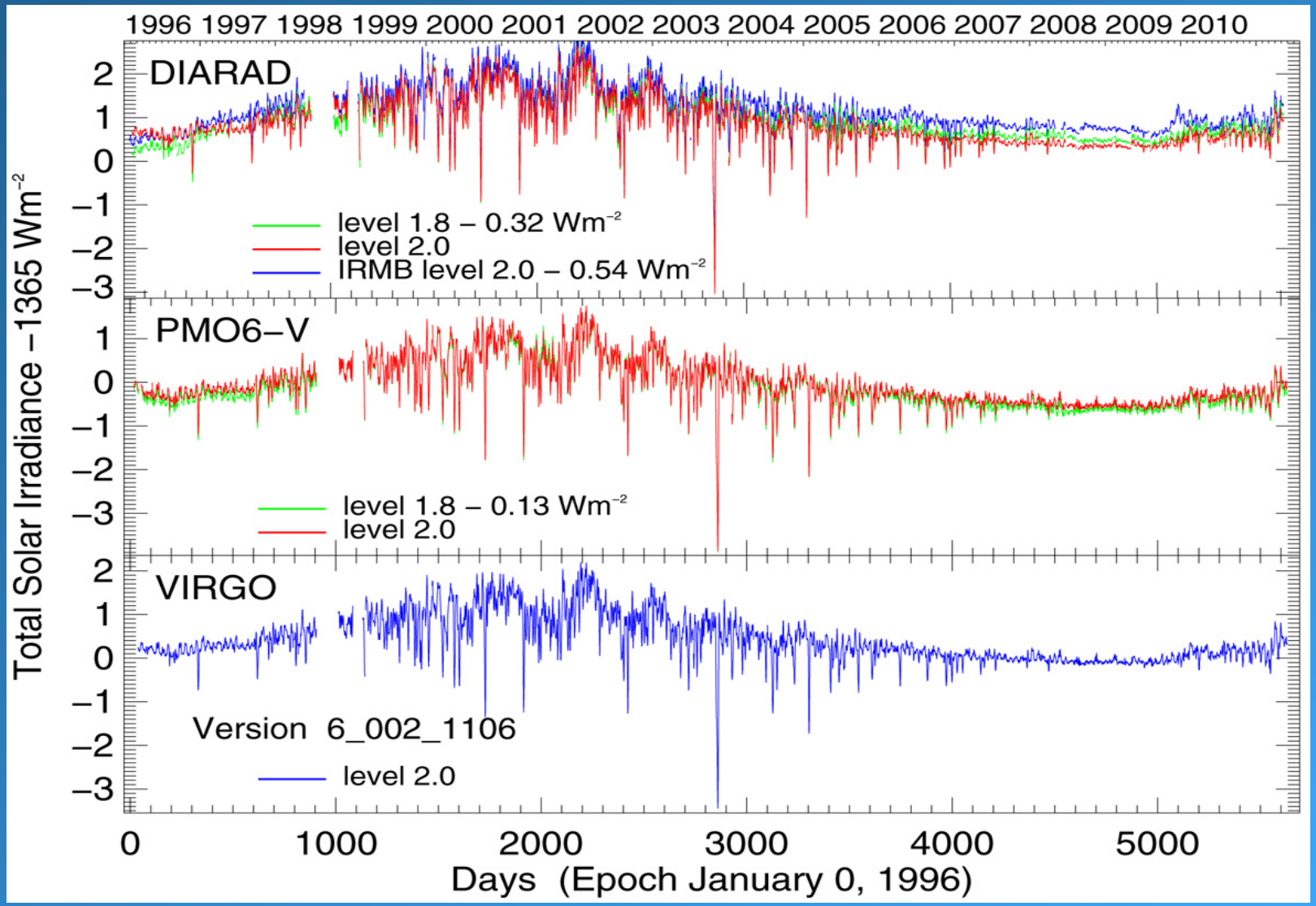
VIRGO Radiometry

Also level 1.8 data show a different behaviour

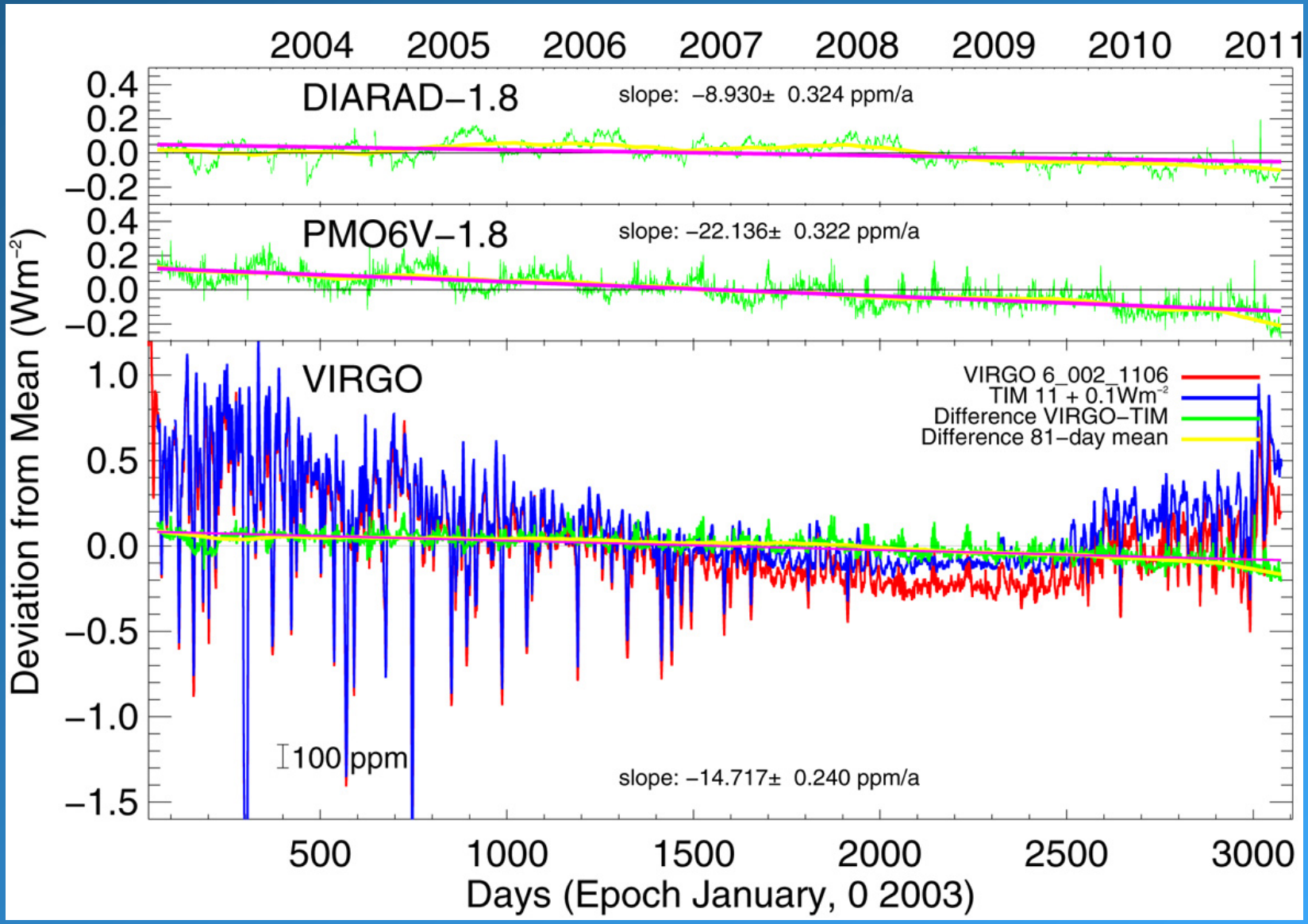


VIRGO Radiometry

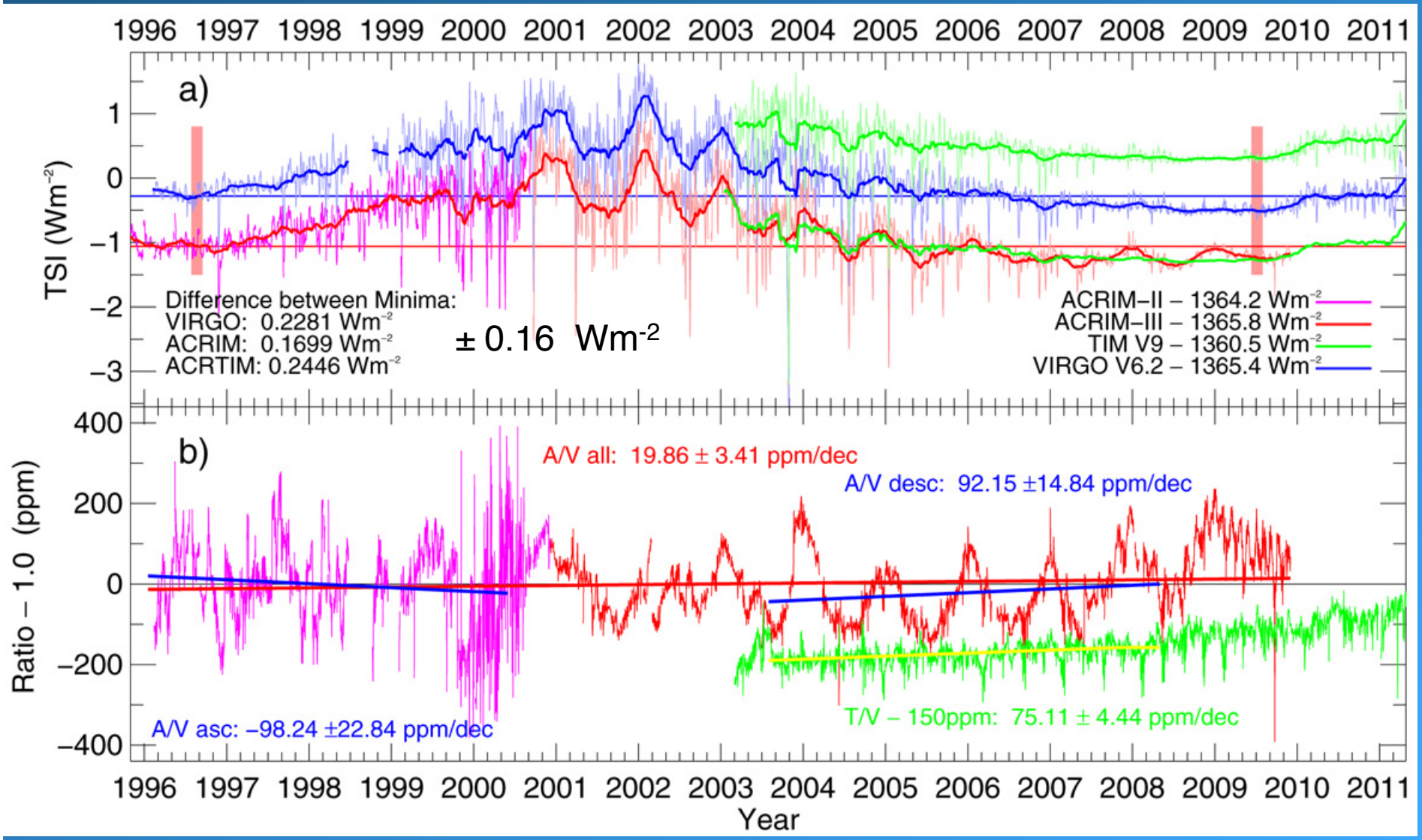
These level-2 data are the final result (note the difference to the IRMB level2)



VIRGO Radiometry



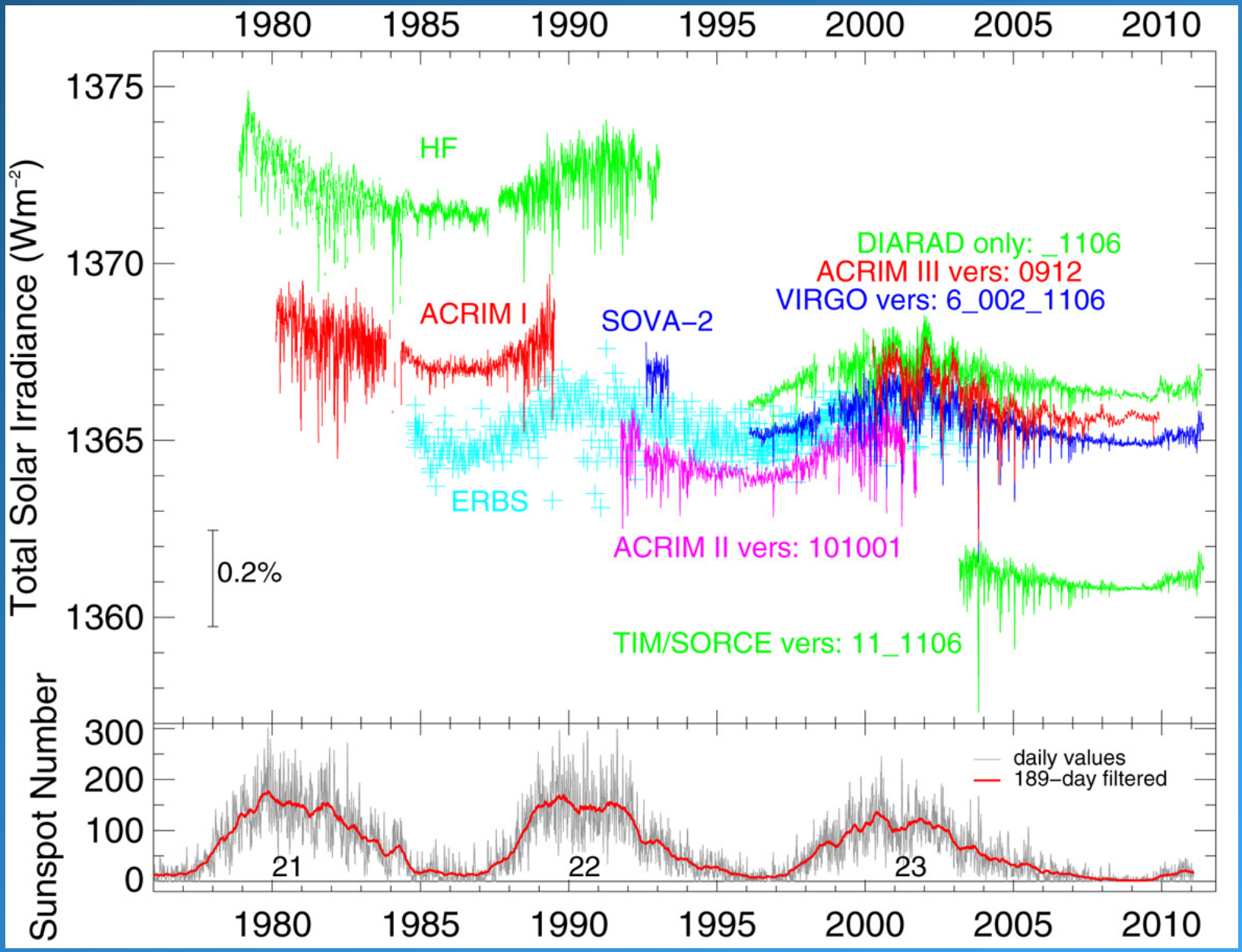
VIRGO Radiometry



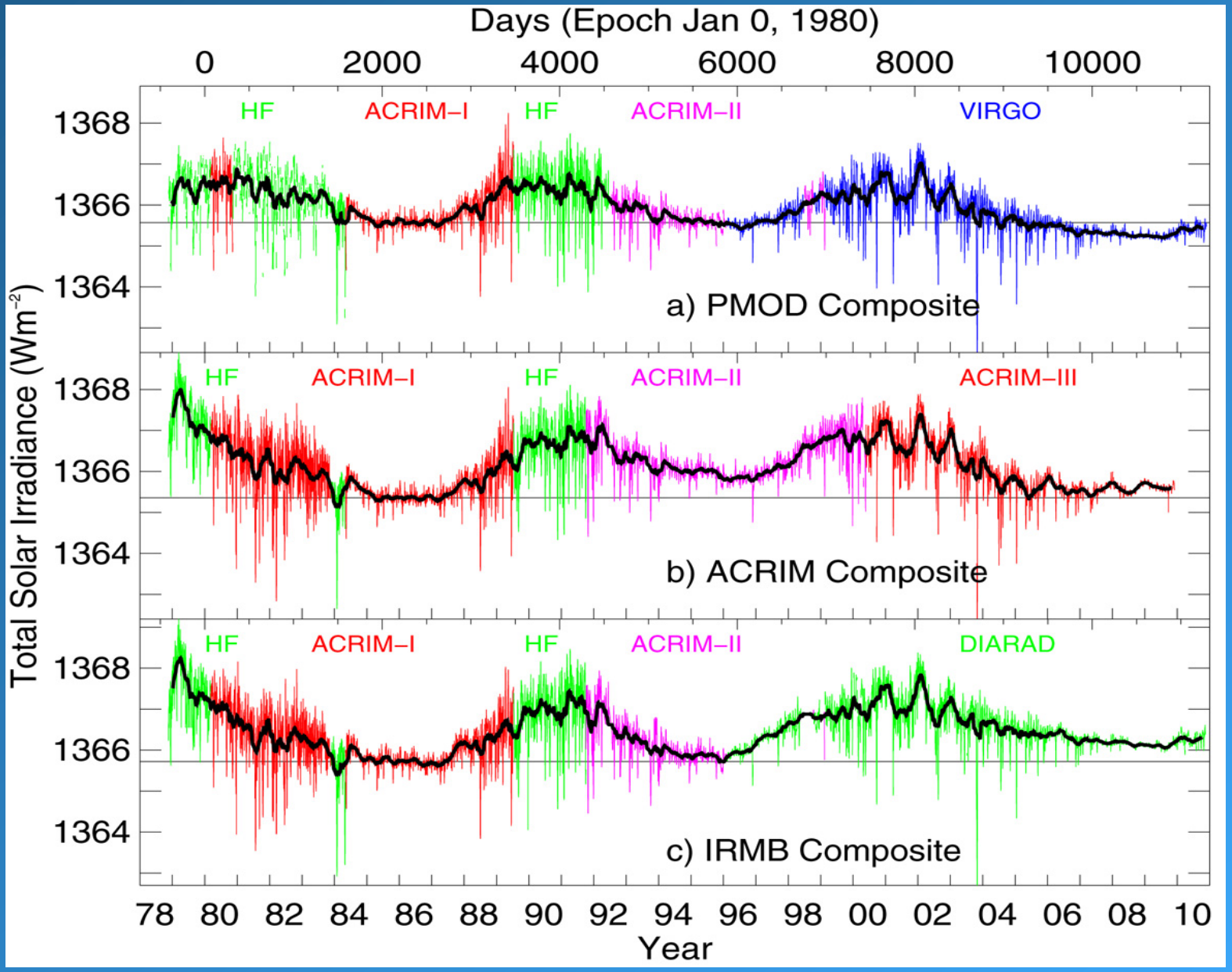
VIRGO TSI conclusions

- Two radiometers of different type are important and provide information about possible non-exposure dependent changes
- The recent minimum in 2009 is lower by 0.23 ± 0.16 Wm^{-2} than the minimum in 1996 – is this real?
- The amplitude of cycle 23 as determined by VIRGO (0.90 or corrected for trend 0.79 Wm^{-2}) may be too large by about 50 ppm

TSI Database 1978 to present



TSI Database 1978 to present



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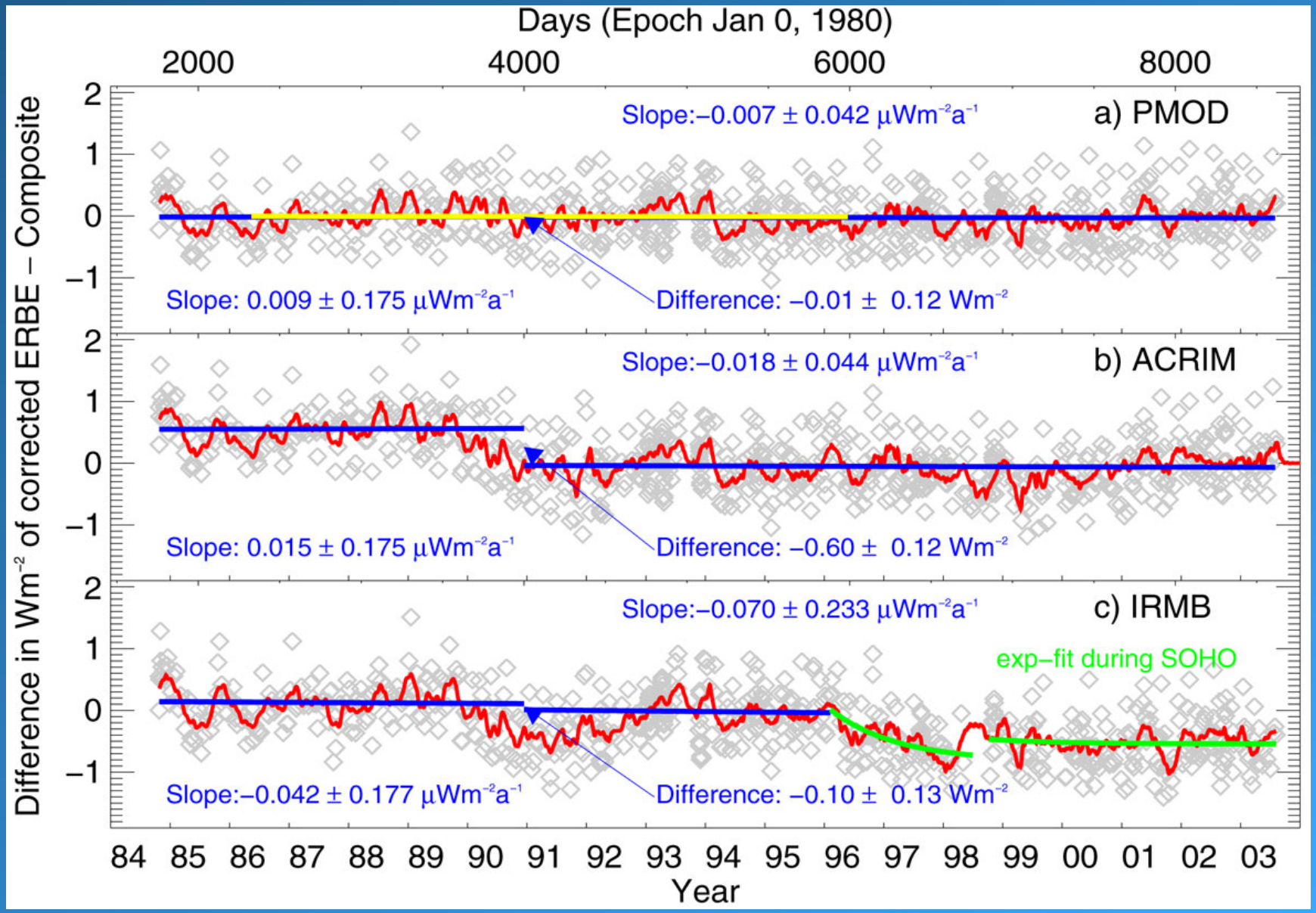
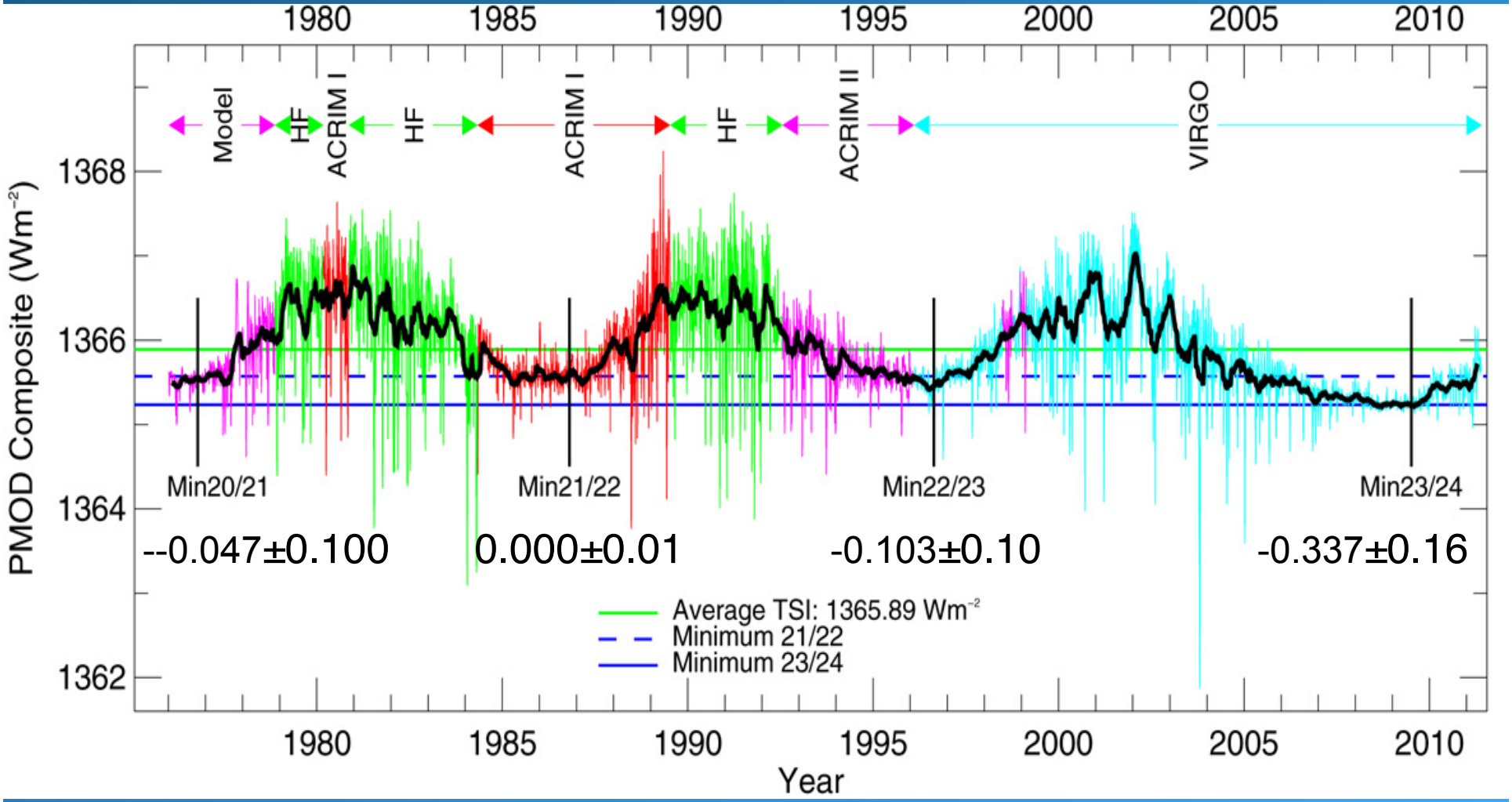
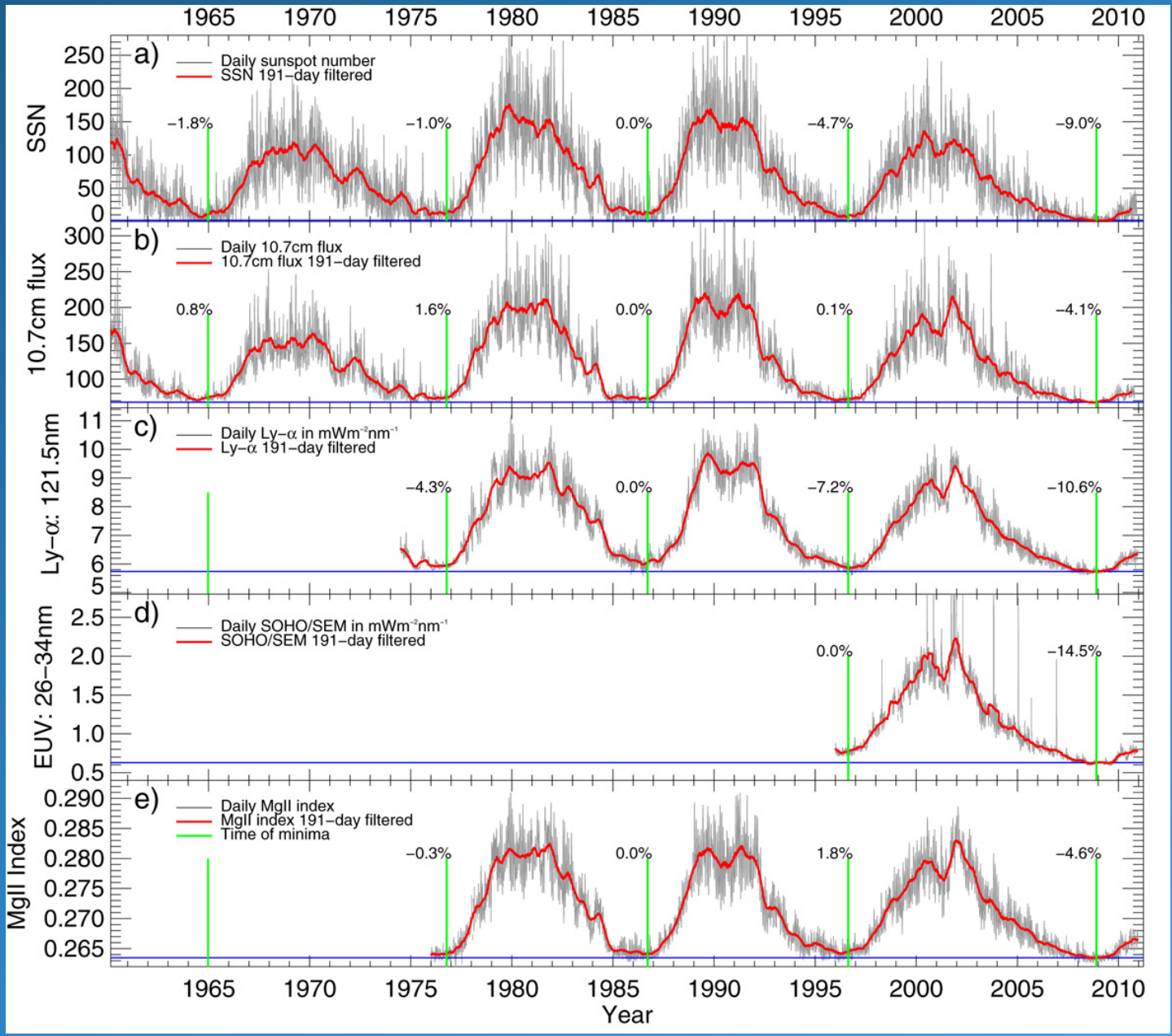


PMOD Composite



How can we explain the low minimum, is there a trend?



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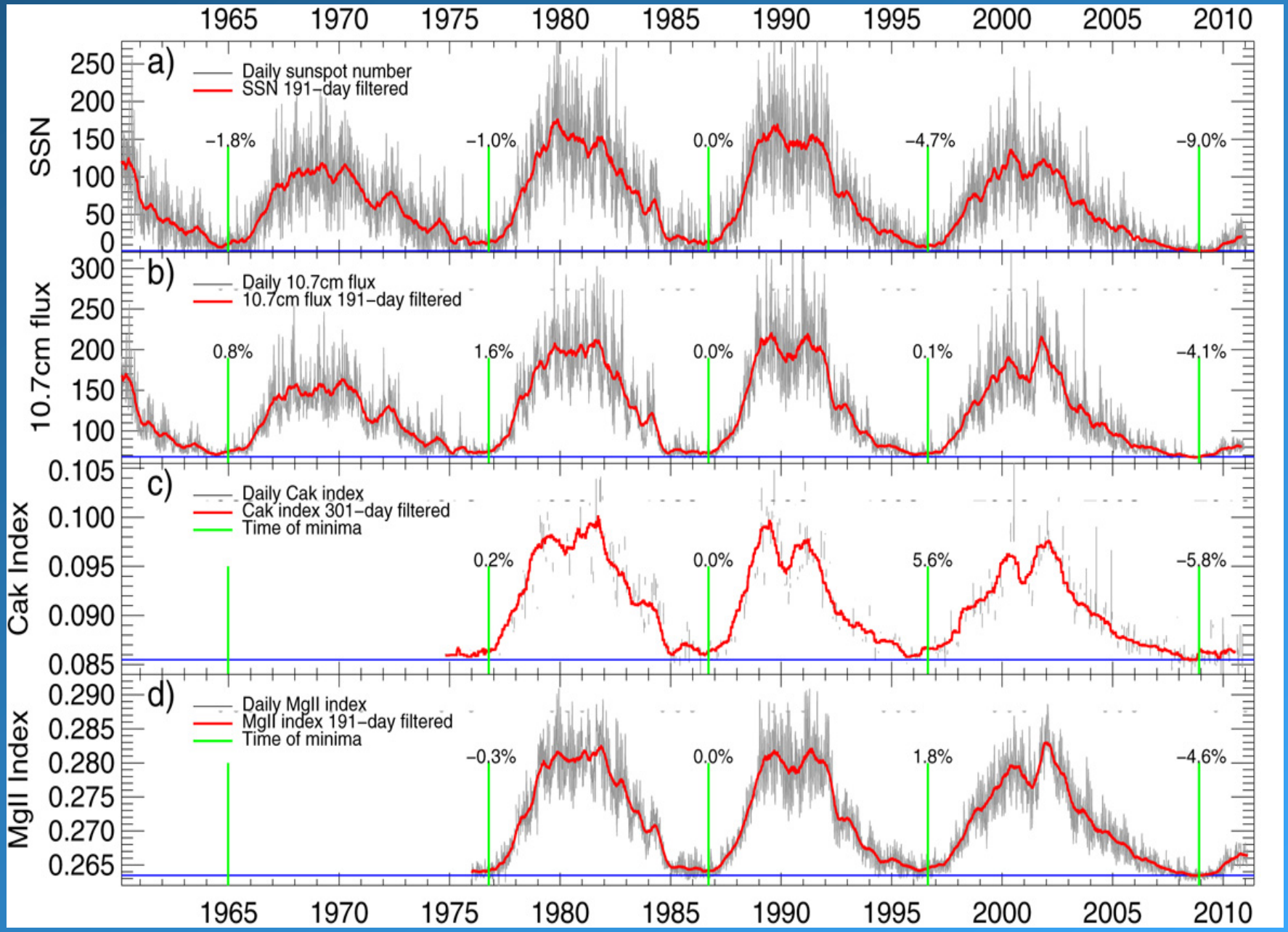

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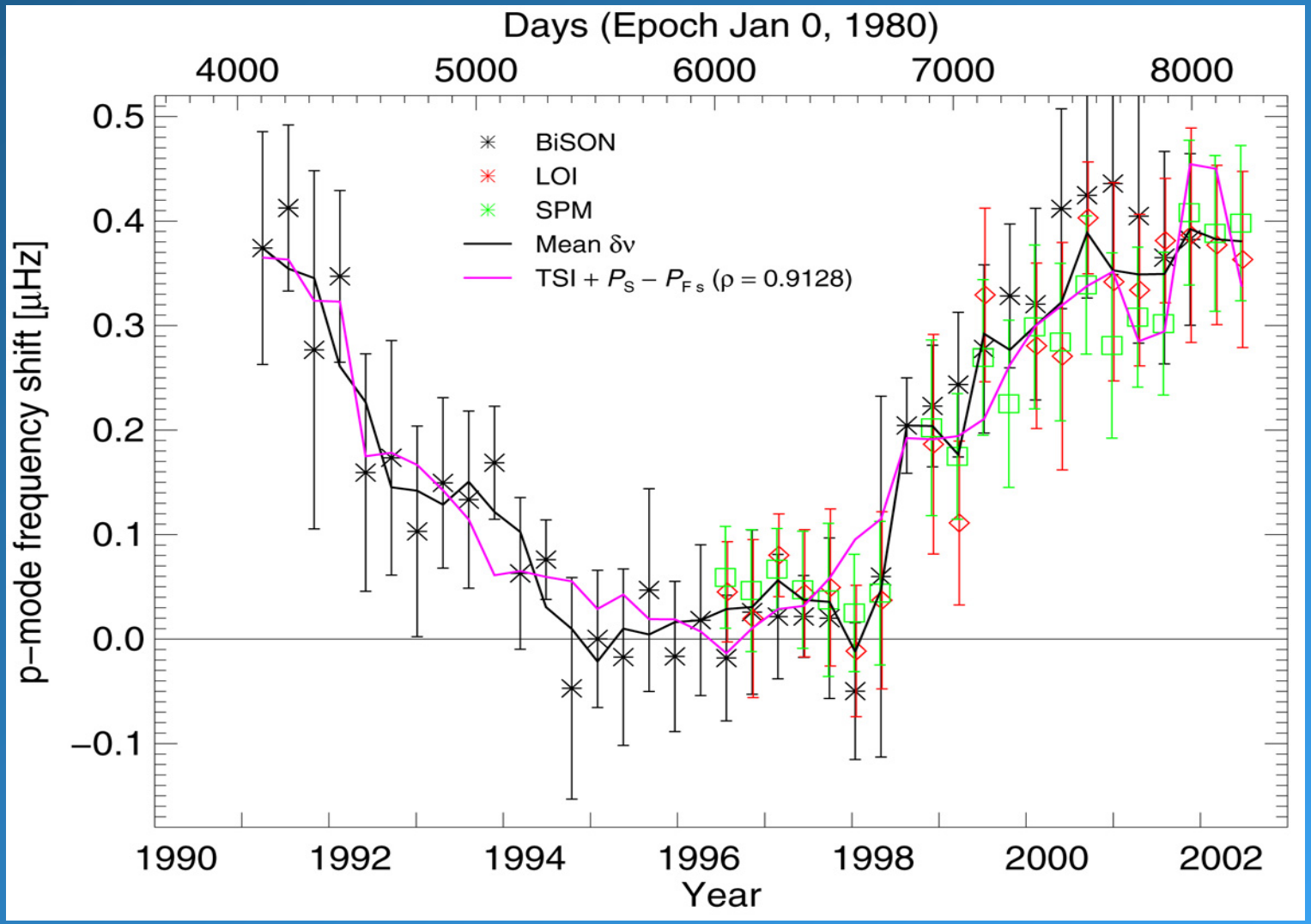

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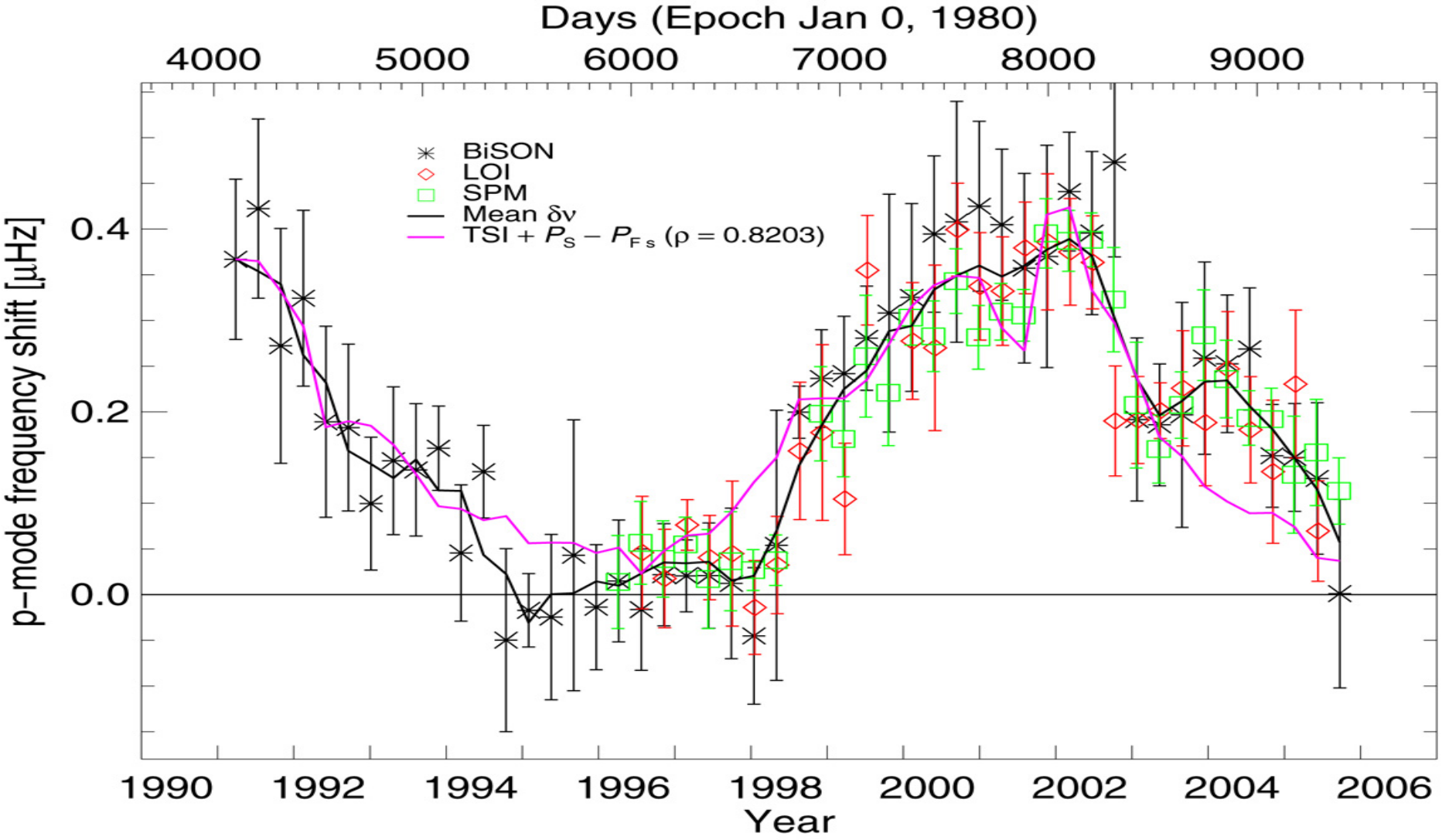
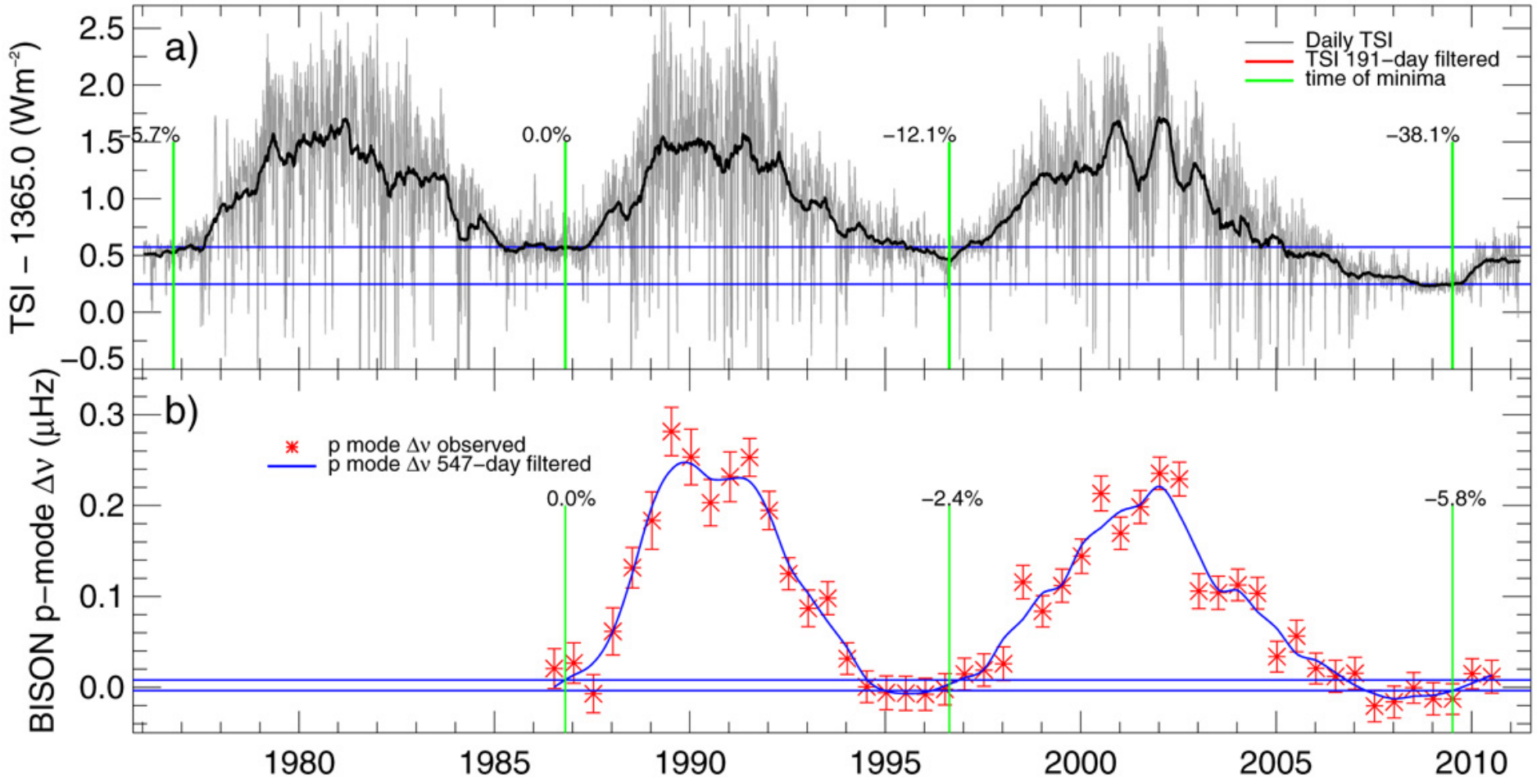
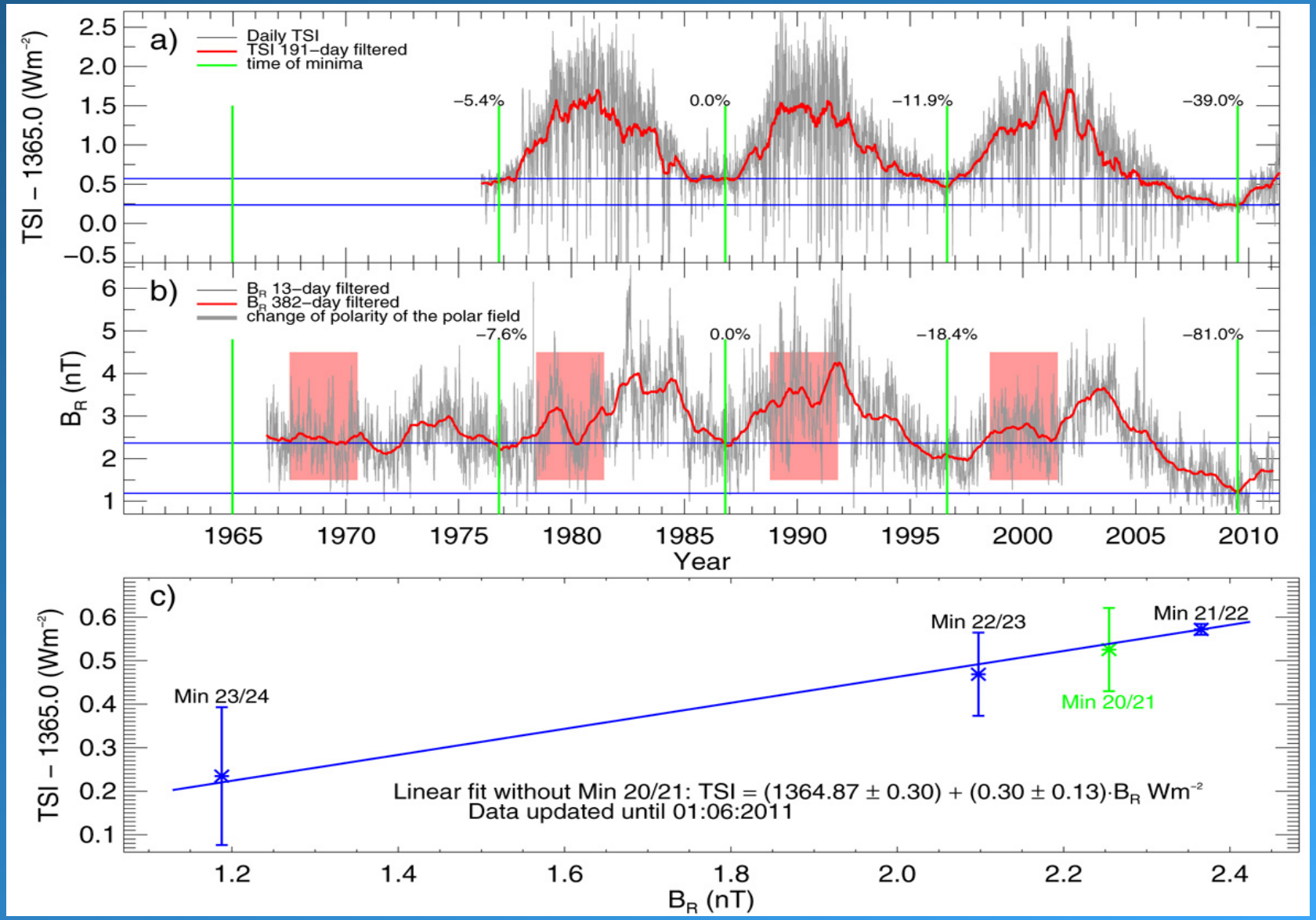


How can we explain the low minimum, is it a trend?

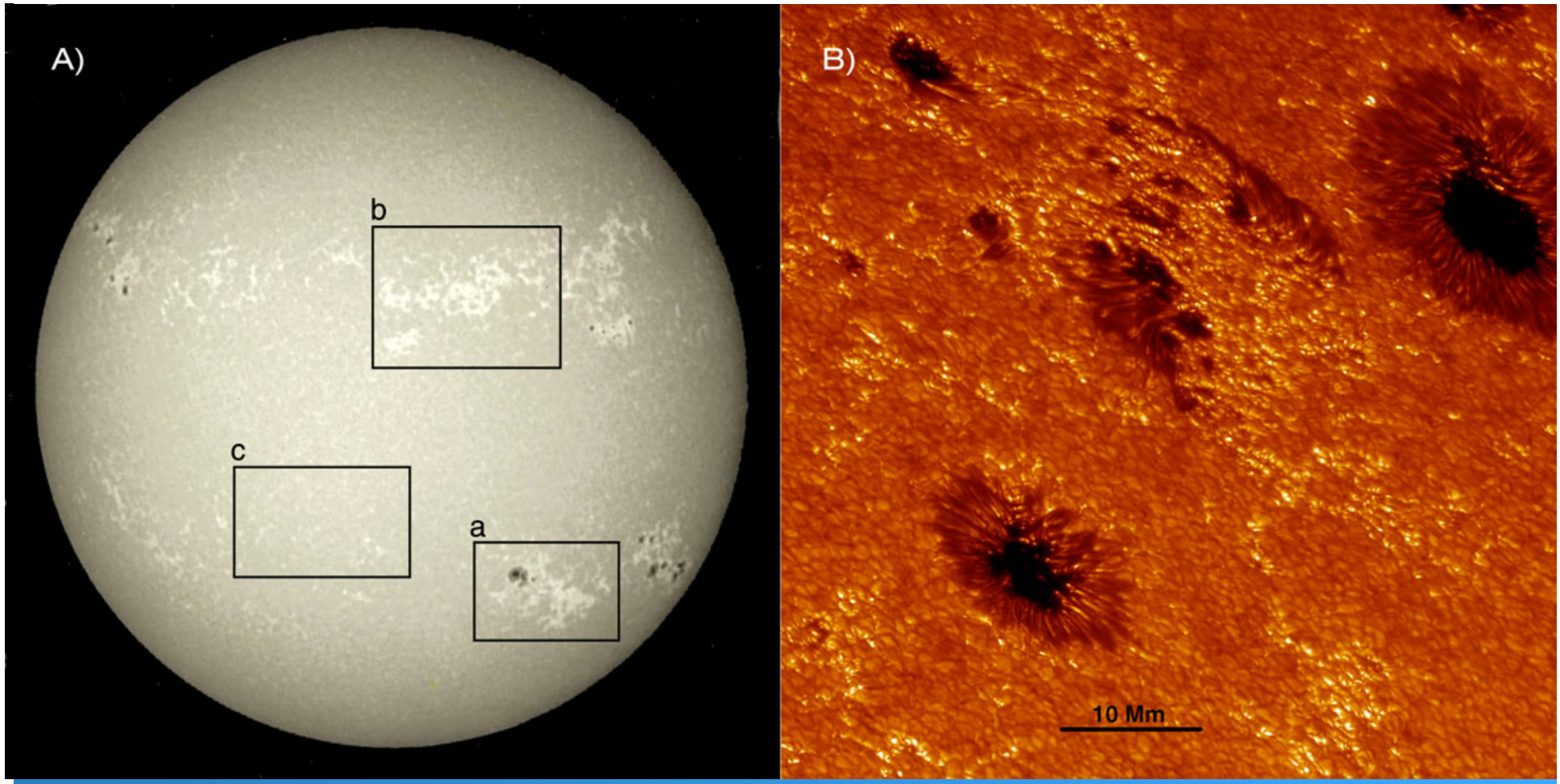


Indeed is may be part of a trend

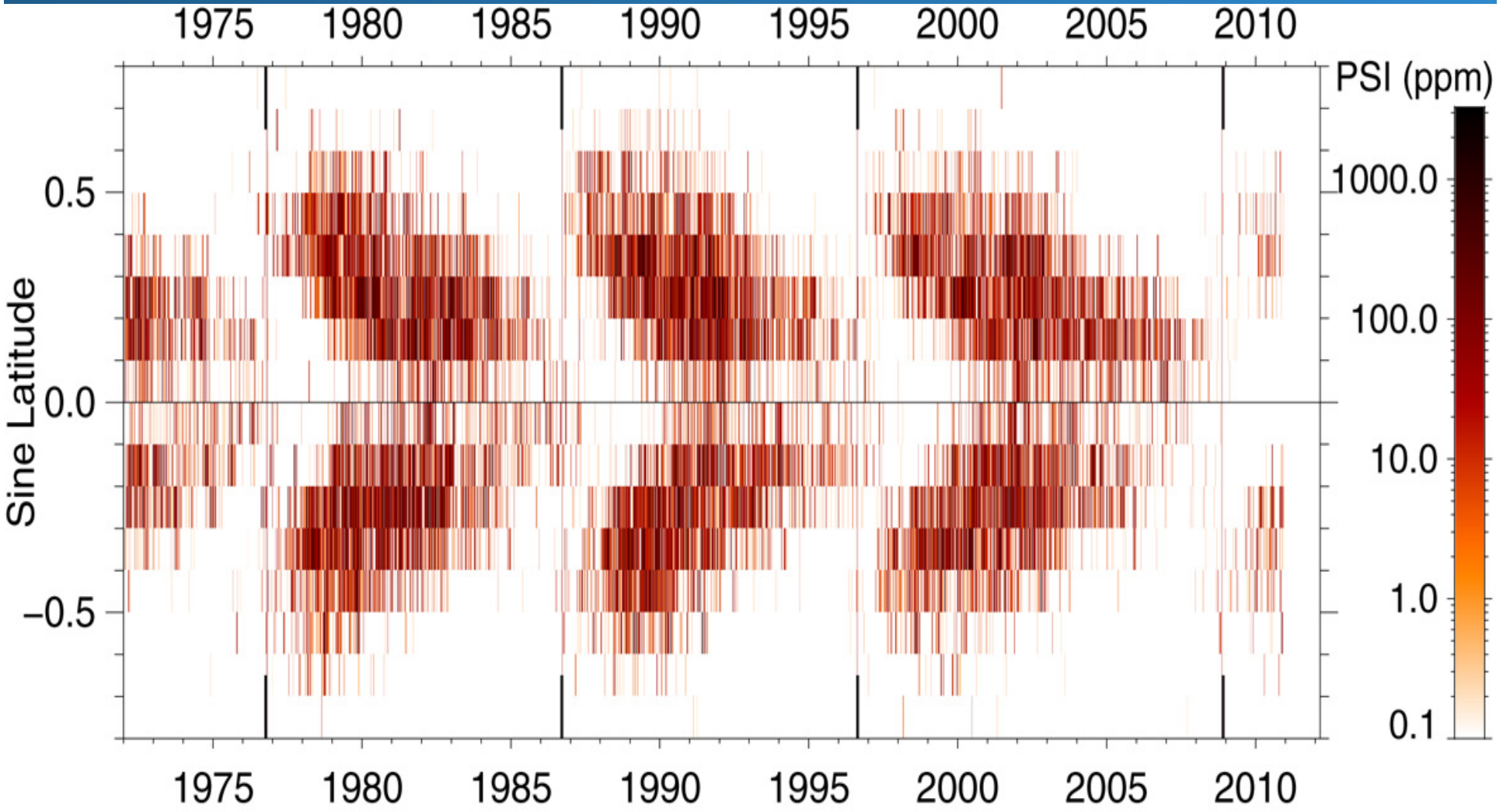


Proxy Model: from 3 to 4 components

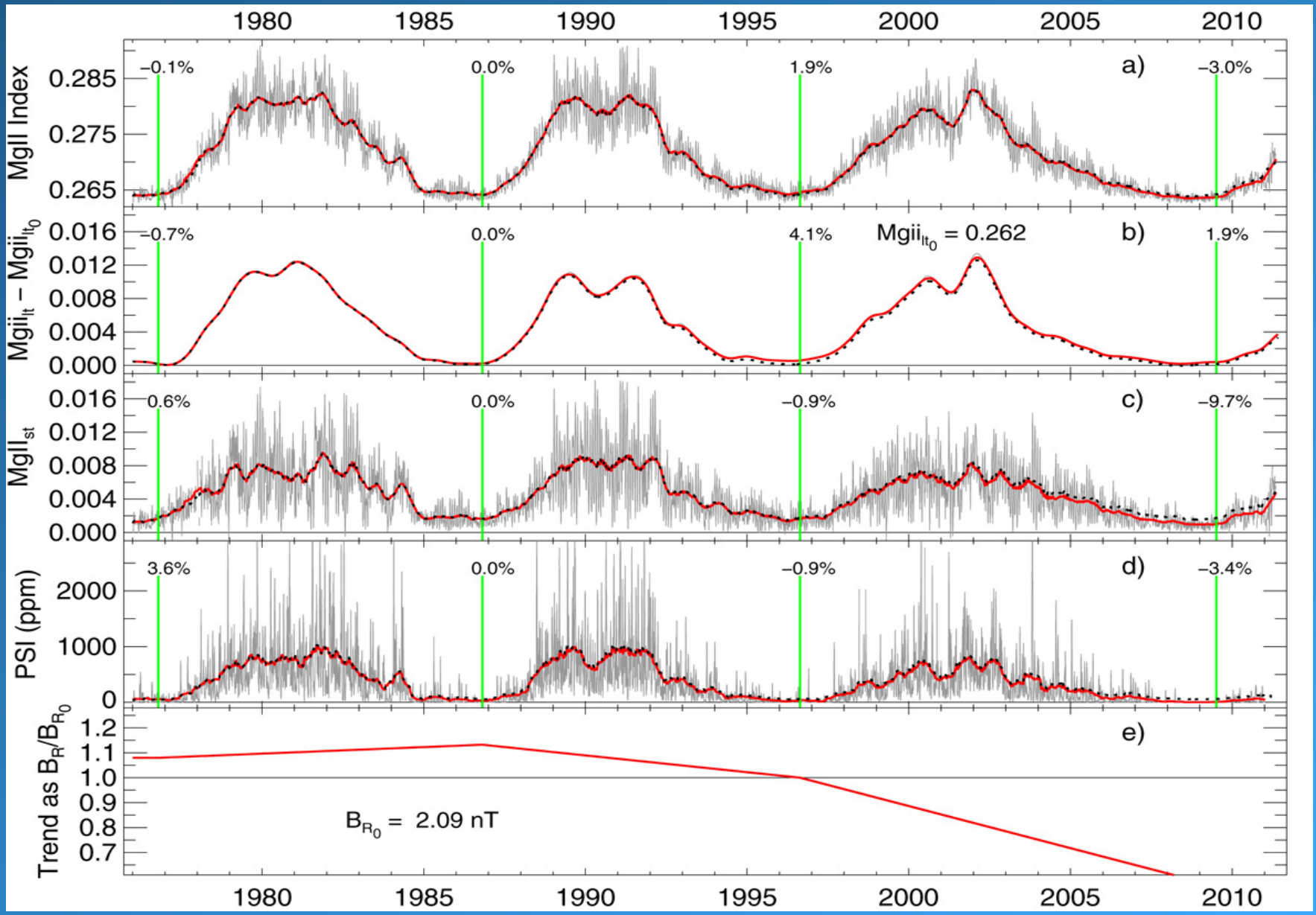
$$S(t) = S_{\mathrm{Q}} + a_{\mathrm{F}} P_{\mathrm{F}}(t) + a_{\mathrm{N}} P_{\mathrm{N}}(t) + a_{\mathrm{S}} P_{\mathrm{S}}(t) + a_{\mathrm{T}} P_{\mathrm{T}}(t)\,,$$



Proxy Model: Photometric Sunspot index (PSI)

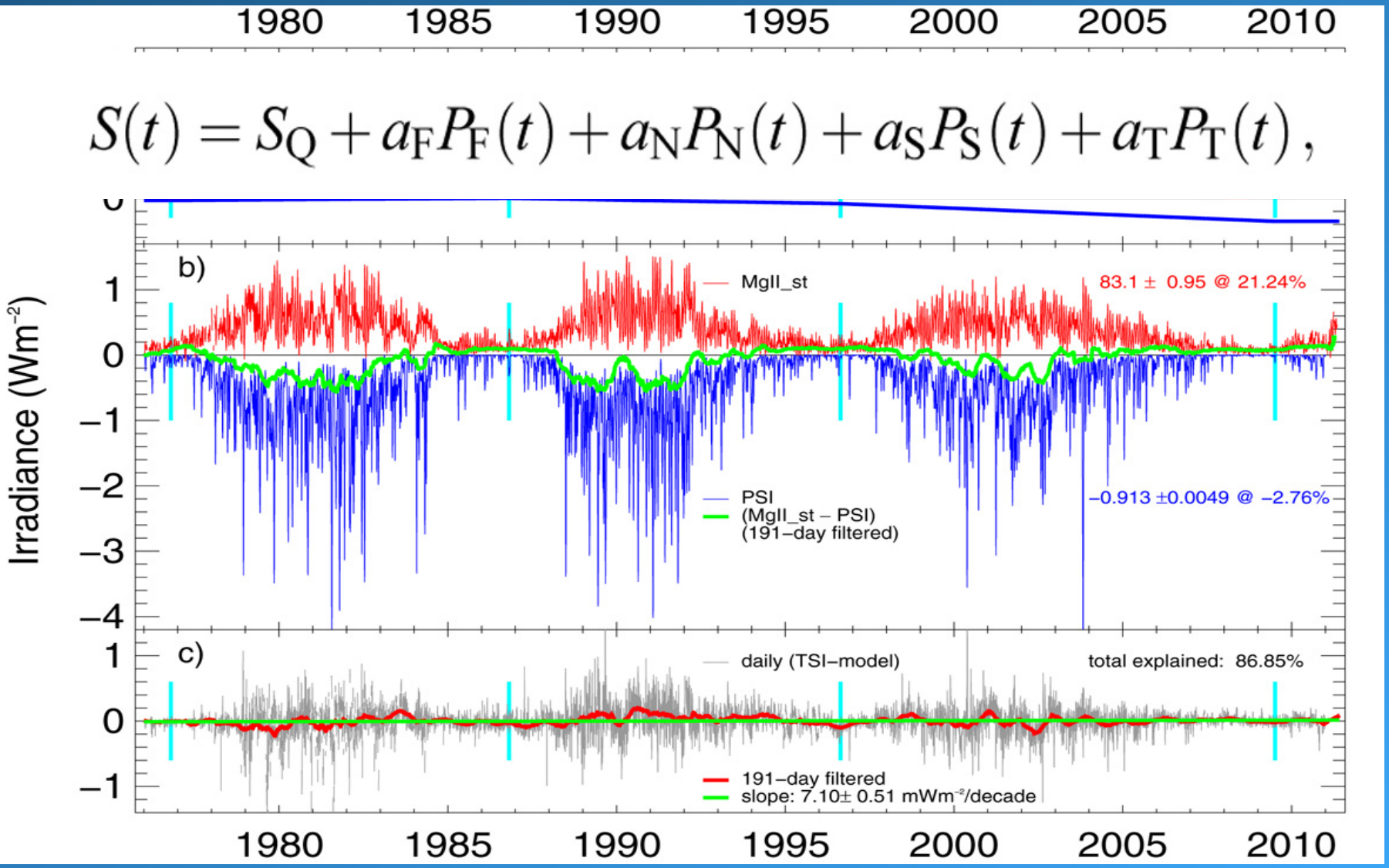


MgII index, faculae, network, PSI and trend



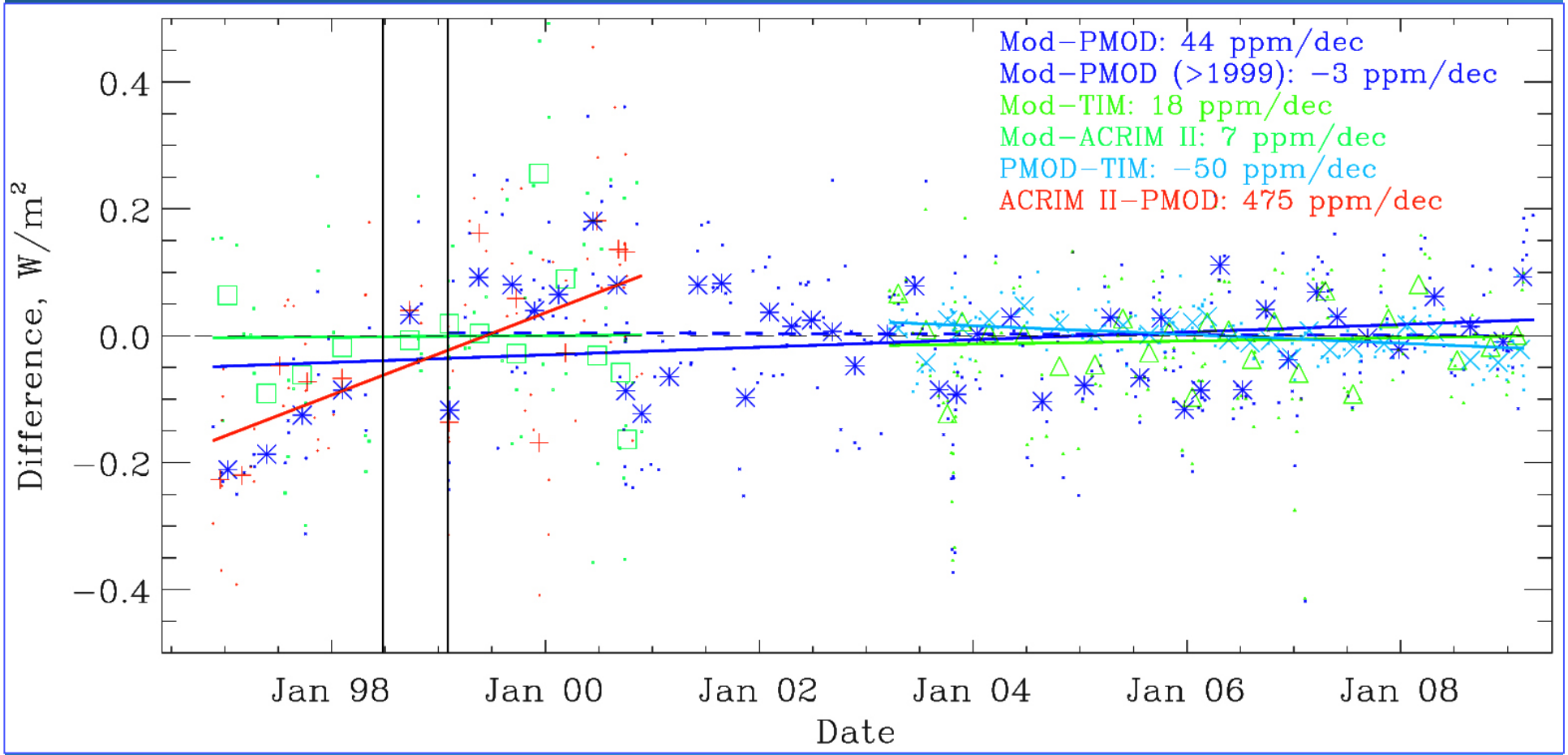
Calibration of the model against TSI over 3 solar cycles

$$S(t) = S_Q + a_F P_F(t) + a_N P_N(t) + a_S P_S(t) + a_T P_T(t),$$



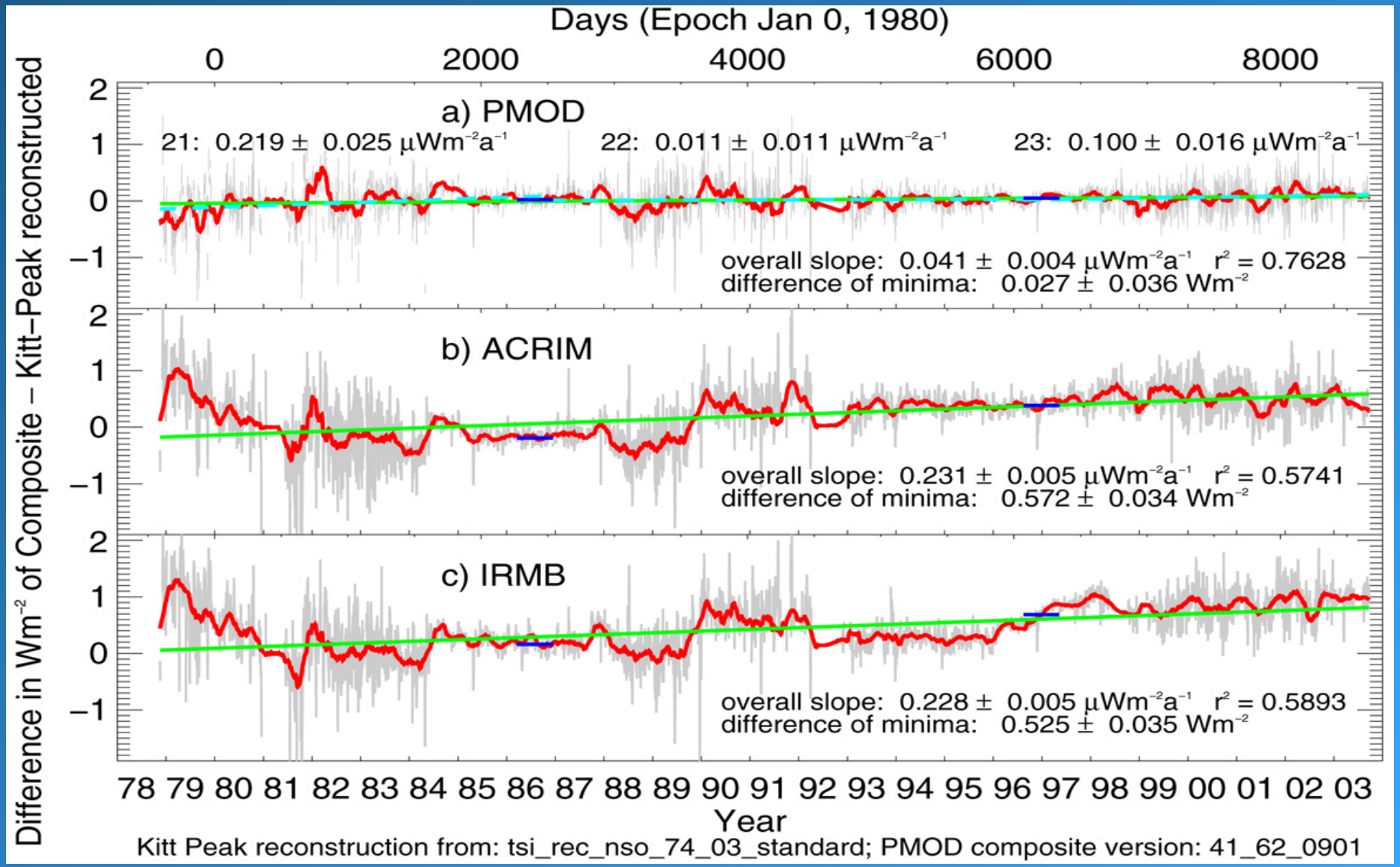
The long-term trend is with 0.30 Wm^{-2}/nT is identical to the directly determined 0.30 ± 0.14 Wm^{-2}/nT from the direct correlation.

Comparison with SATIRE-S over cycle 23



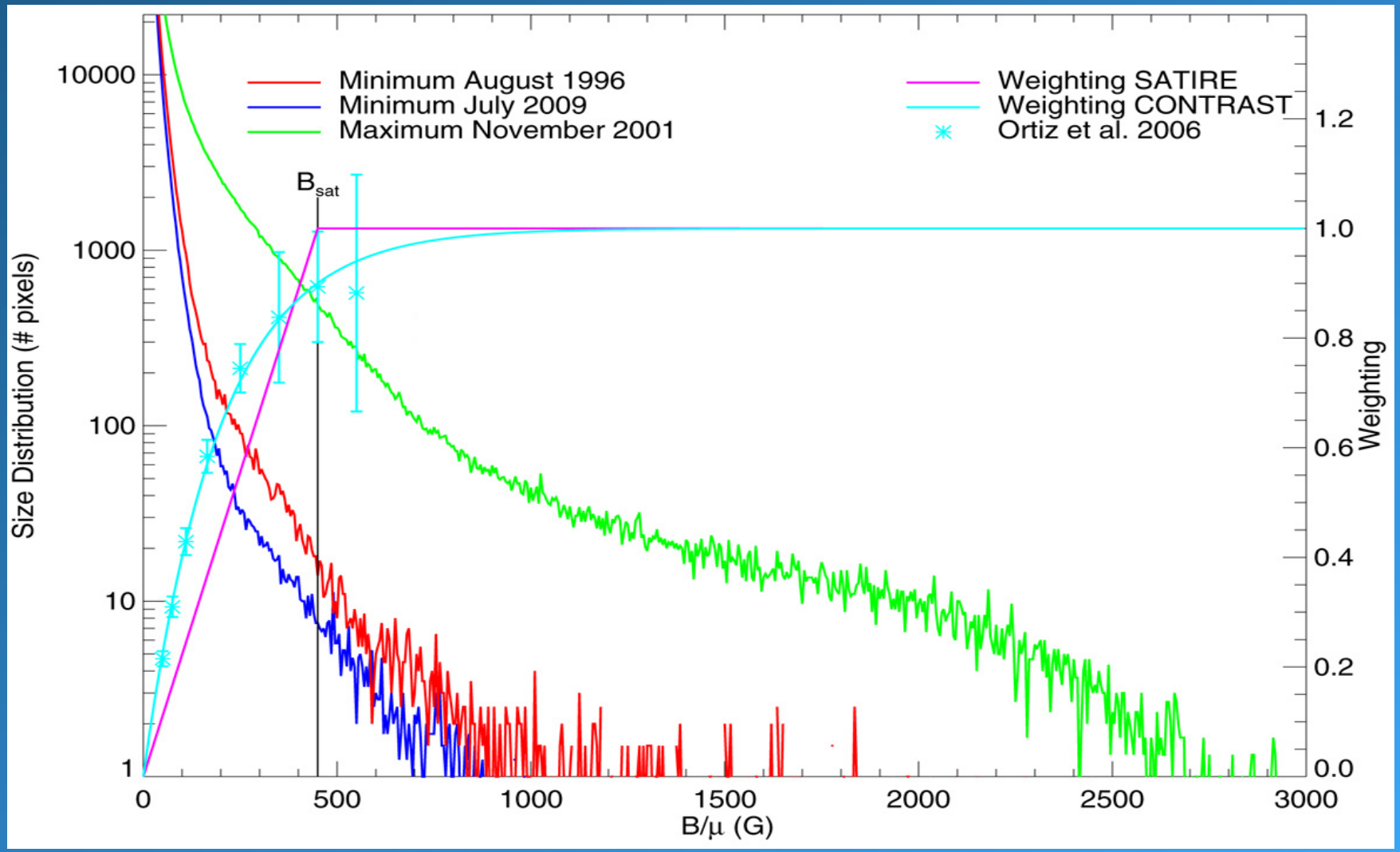
From Krivova, Solanki and Schmutz, A&A, in press, 2011

Comparison with SATIRE-S over from 1975-2003



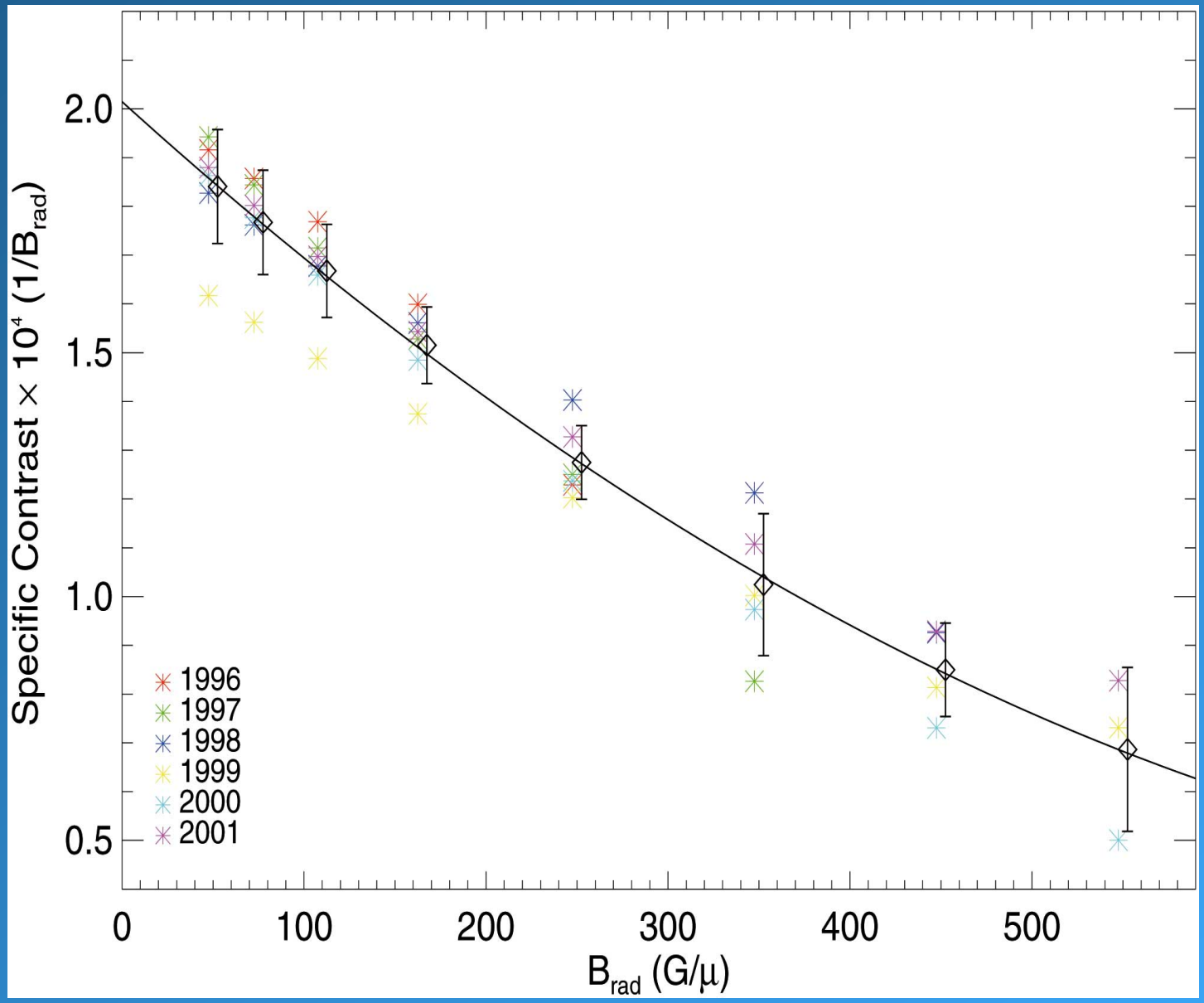
Data from Wenzler et al., A&A, 460, 583, 2006

Basic principle of the SATIRE-S type models

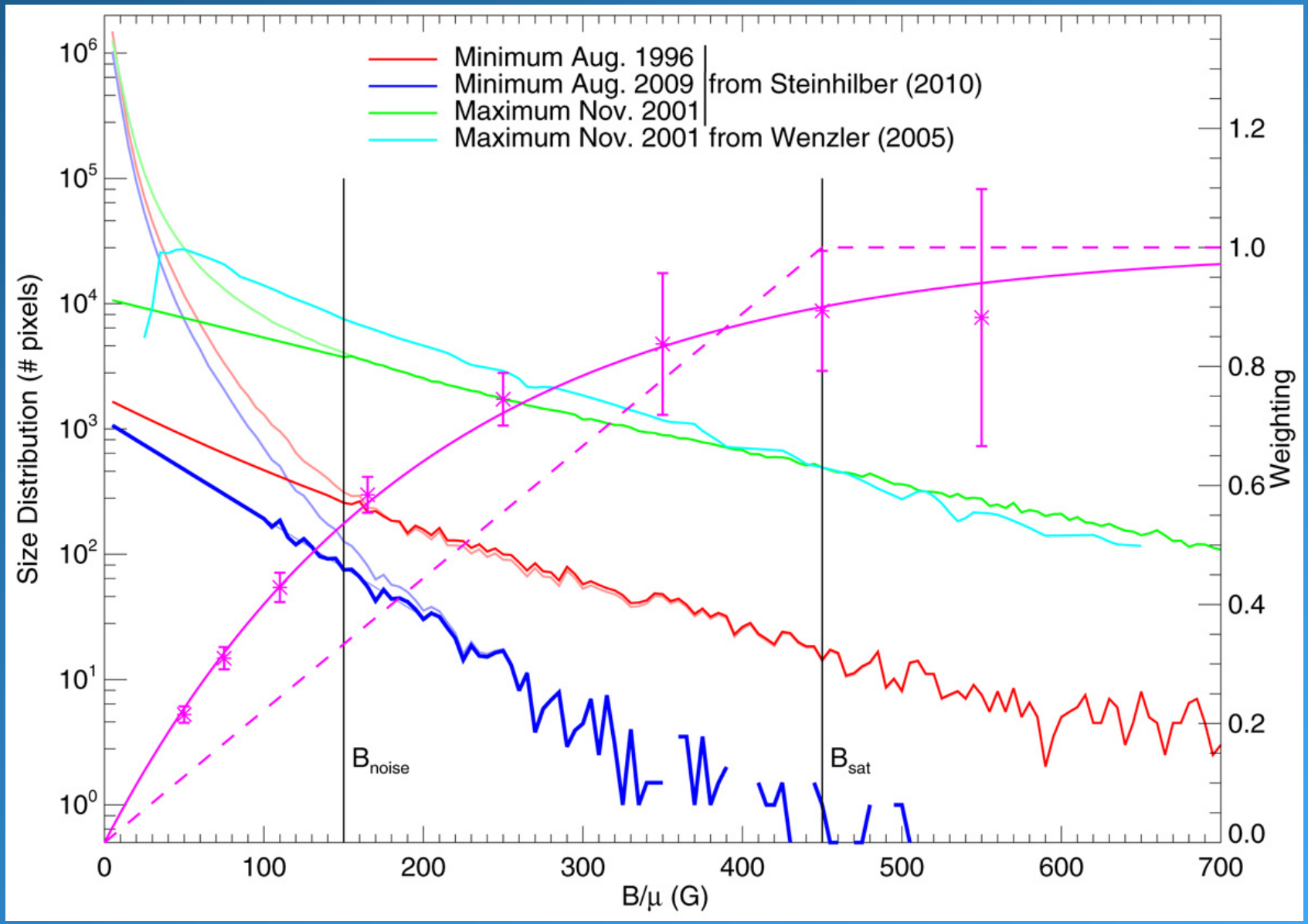


Data from Steinhilber, A&A, 523, A39, 2010

Possible explanations of the TSI trend



Possible explanations of the TSI trend



Conclusions for TSI over the last 3 Cycle

- The PMOD composite is a reliable representation of TSI. The absolute value, however, is still controversial.
- The 4-component model for TSI with PSI, a short and long-term MgII index and a trend from B_R can explain 84% of the variance. As PSI and MgII alone cannot explain the trend, it must have another origin.
- A global temperature change of the Sun between the last two minima of only about 0.25 K is needed to explain the trend. However, the increasing contrast of faculae and network with decreasing magnetic field could be an alternative explanation.
- The long-term trend observed in TSI is related to B_R, that is to the strength of the activity which would mean that the magnetic field from the ephemeral regions, which defines the 'quiet' sun, changes slightly with the strength of activity.
- With these results TSI can be reconstructed back to 1915 from (a) PSI deduced from observations of sunspots by the Royal Greenwich Observatory, (b) CaK index from Mt.Wilson and (c) B_R from the aa index.

This is the reconstruction