27-Day Modulation of Cosmic Ray Intensities During the Last Two Solar Minima

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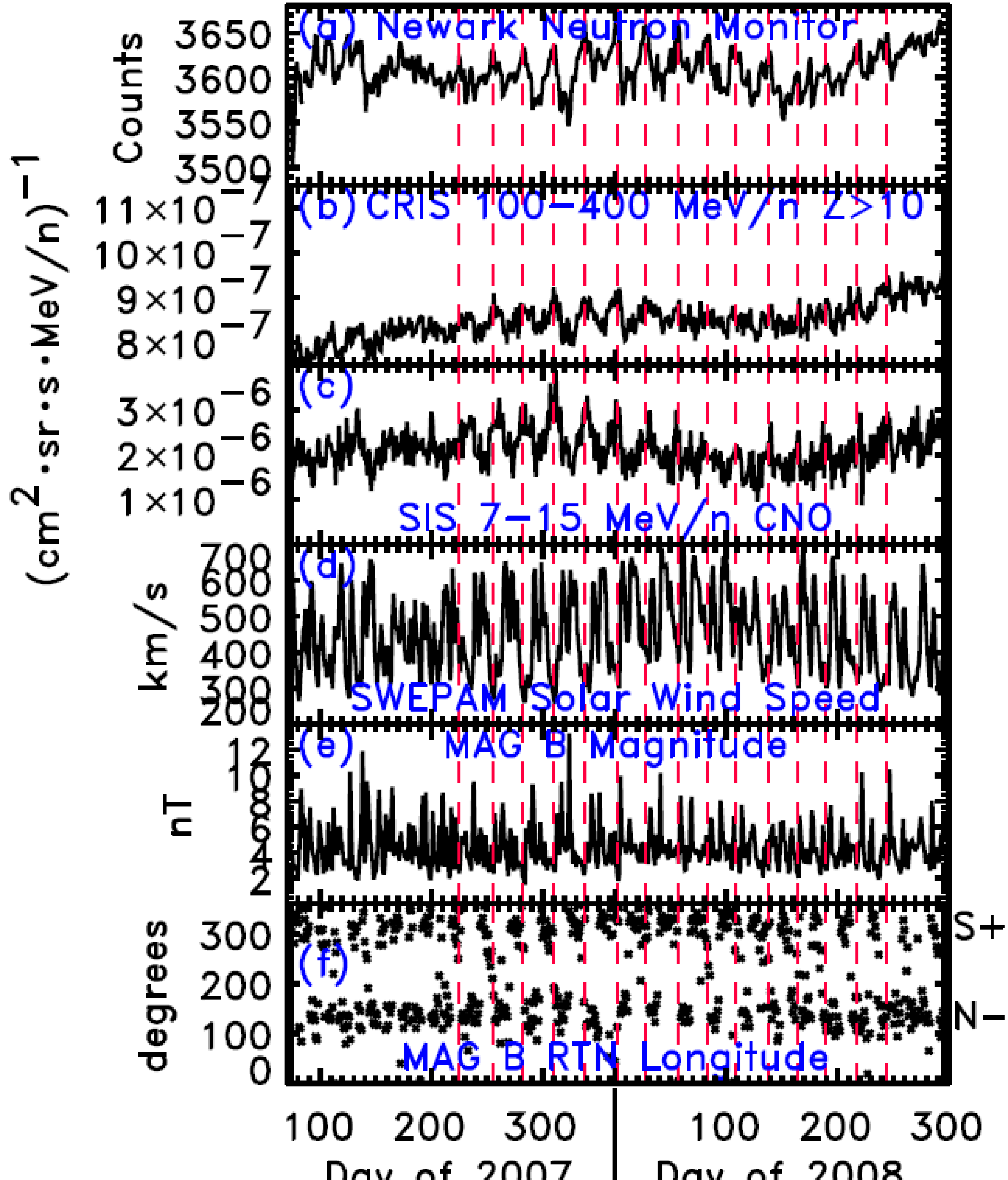

2007-08 A<0

~27-day intensity variations often appear in GCRs and in ACRs, associated with recurring high-speed solar wind streams. Although the heliospheric current sheet (HCS) is generally crossed twice per rotation, cosmic ray peaks often occur at only one of the crossings.

Leske *et al., Proc 32nd ICRC* **11**, 194 (2011)

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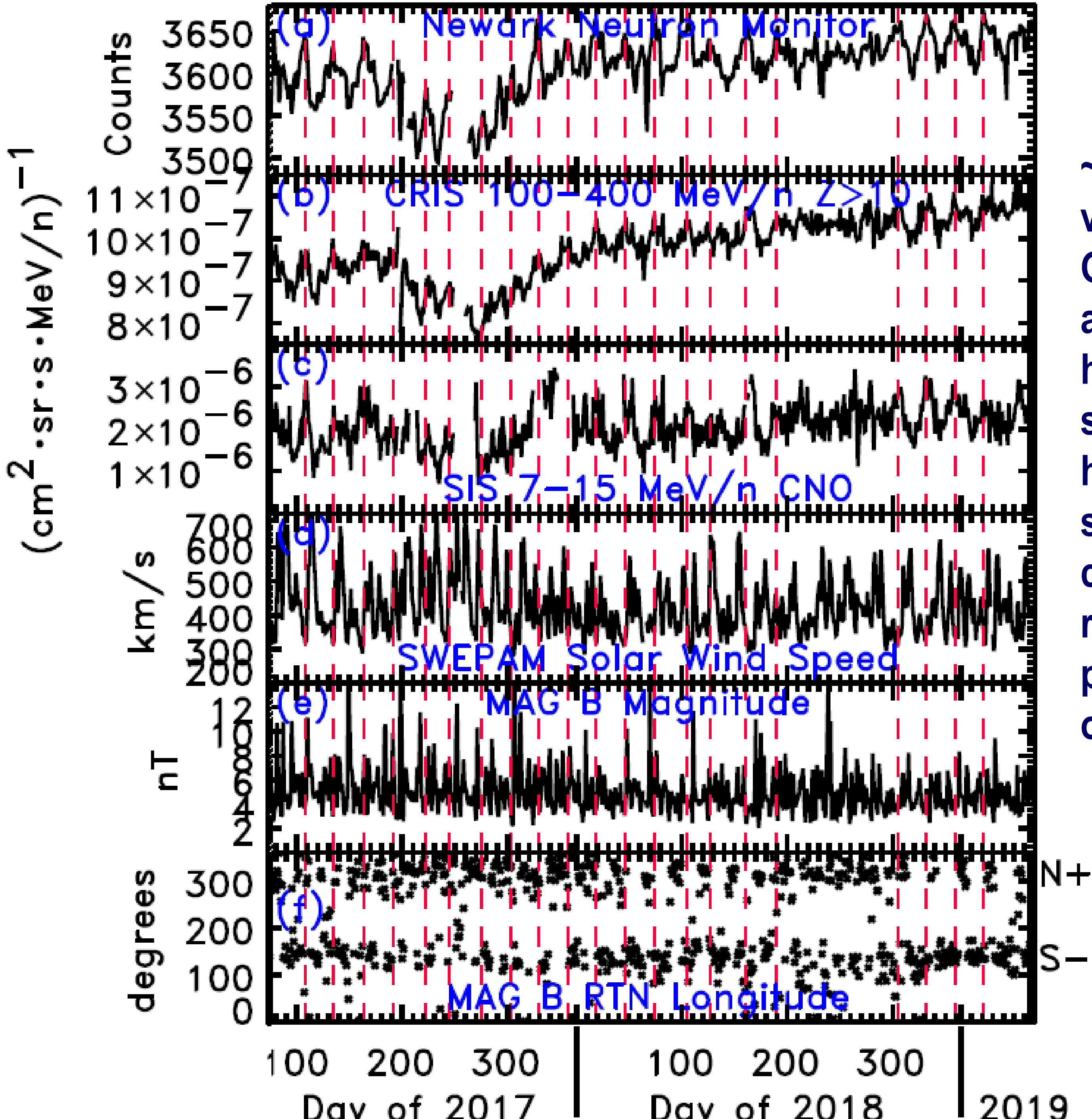
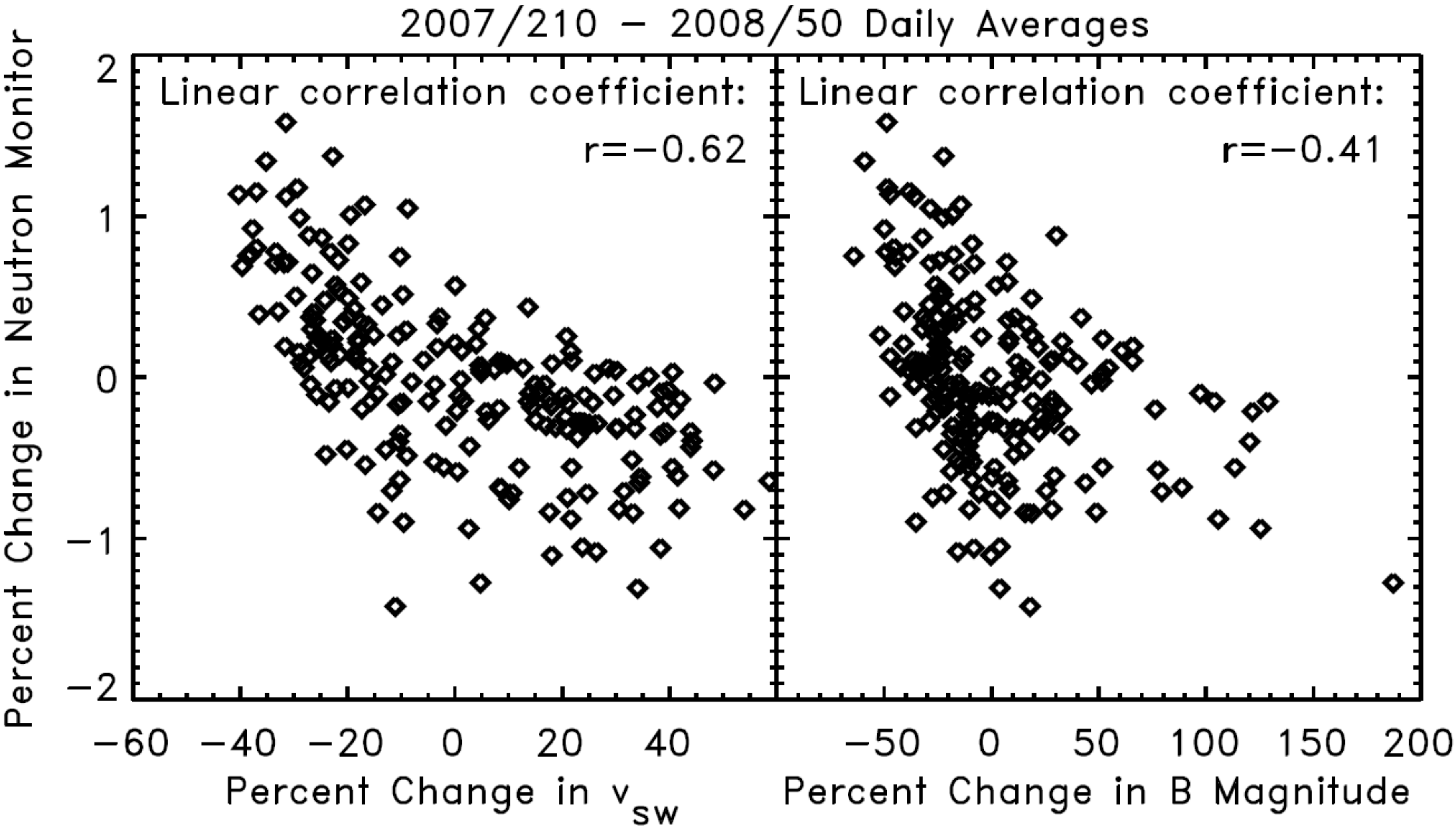


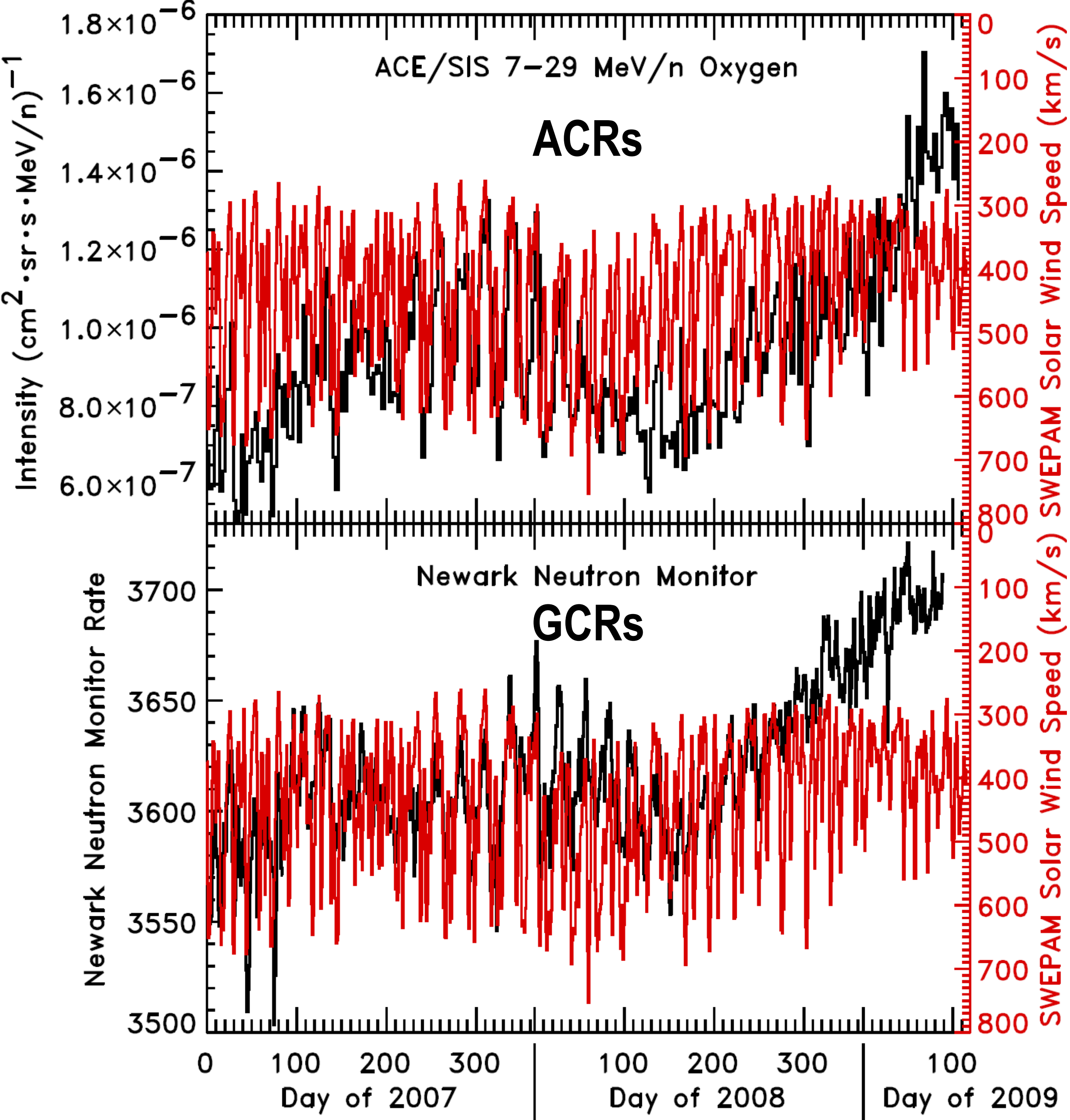
2017-19 A>0

~27-day intensity variations often appear in GCRs and in ACRs, associated with recurring high-speed solar wind streams. Although the heliospheric current sheet (HCS) is generally crossed twice per rotation, cosmic ray peaks often occur at only one of the crossings.

We looked for correlations between the neutron monitor rate and: *solar wind speed*, *solar wind density*, *solar wind dynamic pressure*, *magnetic field strength*, and *rms variation of the magnetic field*, and find the highest (inverse) correlation with the solar wind speed:

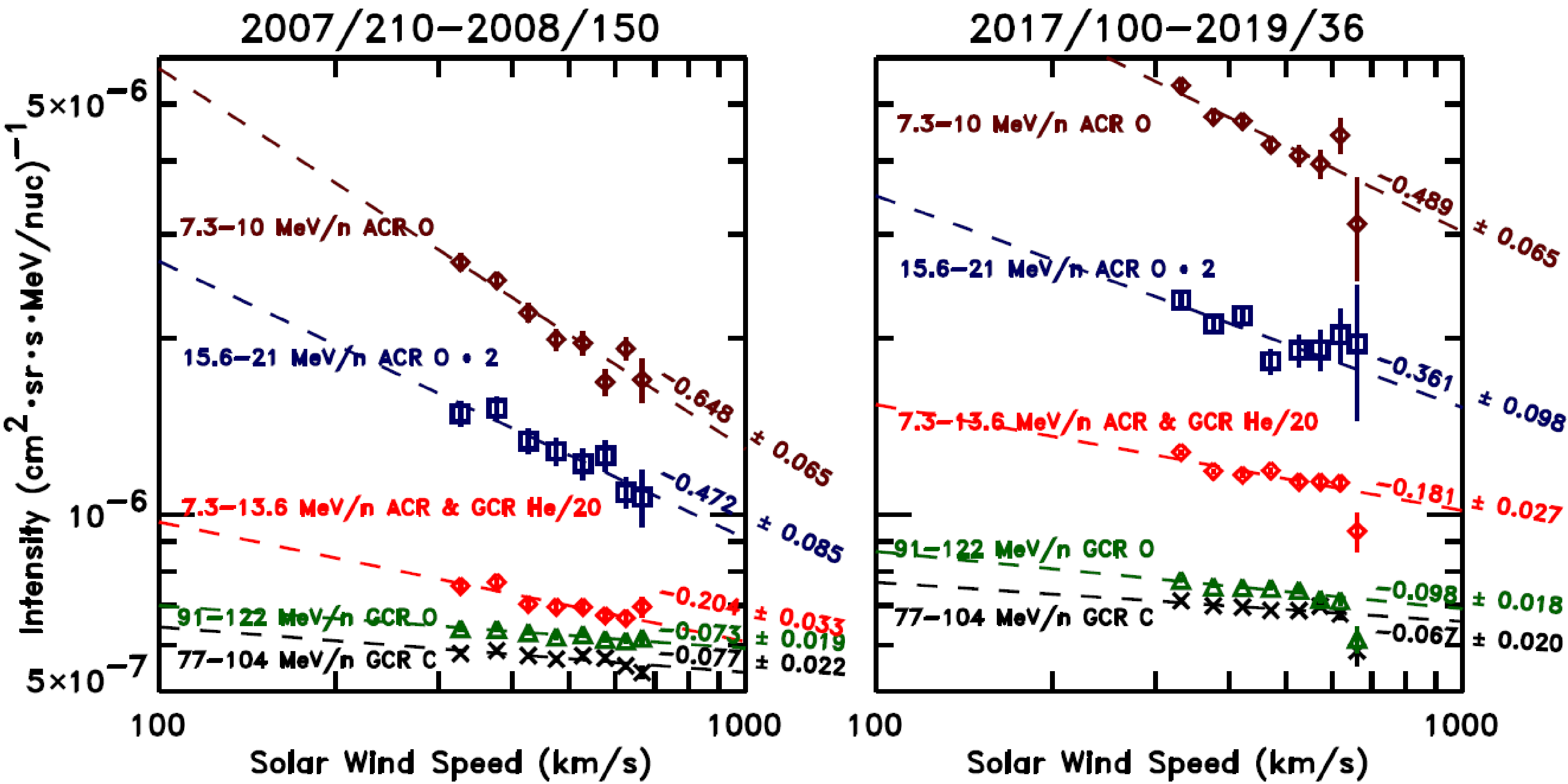


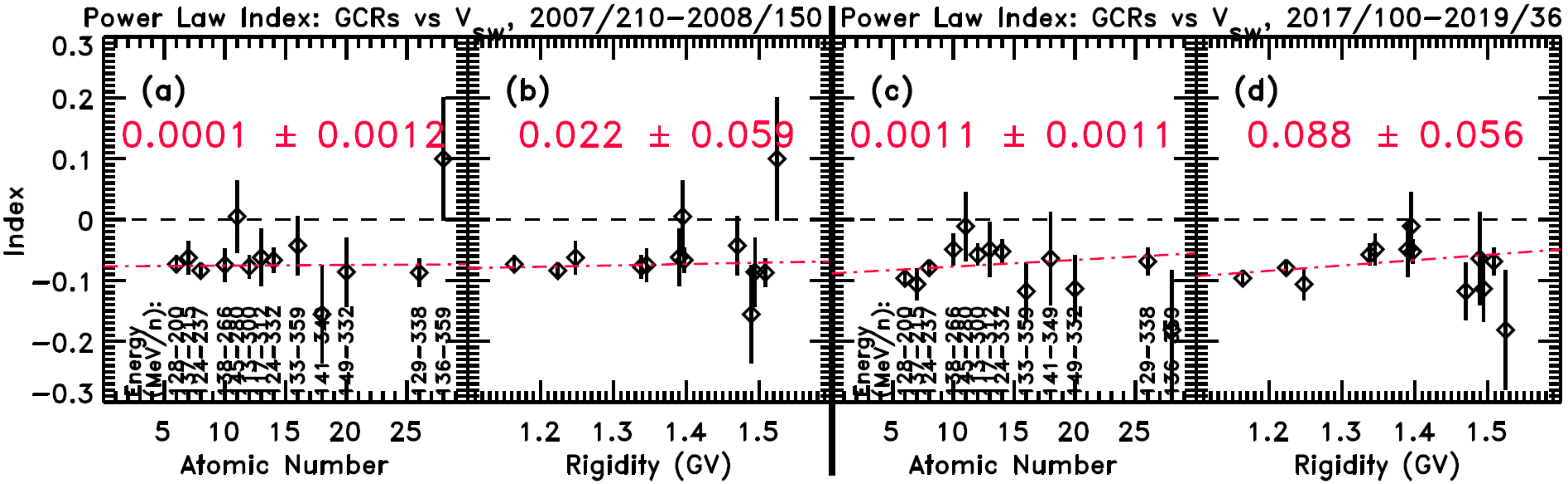
Leske *et al., Proc 32*[nd] *ICRC* **11**, 194 (2011)



We looked for correlations between the energetic particle intensities and: *solar wind speed*, *solar wind density*, *solar wind dynamic pressure*, *magnetic field strength*, and *rms variation of the magnetic field*, and find the best (inverse) correlation with the solar wind speed for both ACRs and GCRs.

Binning the ACR and GCR data in 50 km/s-wide solar wind speed bins, we find good power-law relationships, with ACRs more sensitive to Vsw than GCRs. **Slopes tend to be shallower in the 2017-18 than in the 2007-08 solar minimum, but consistent within uncertainties (biggest difference: ~1.7σ for ACR O)**

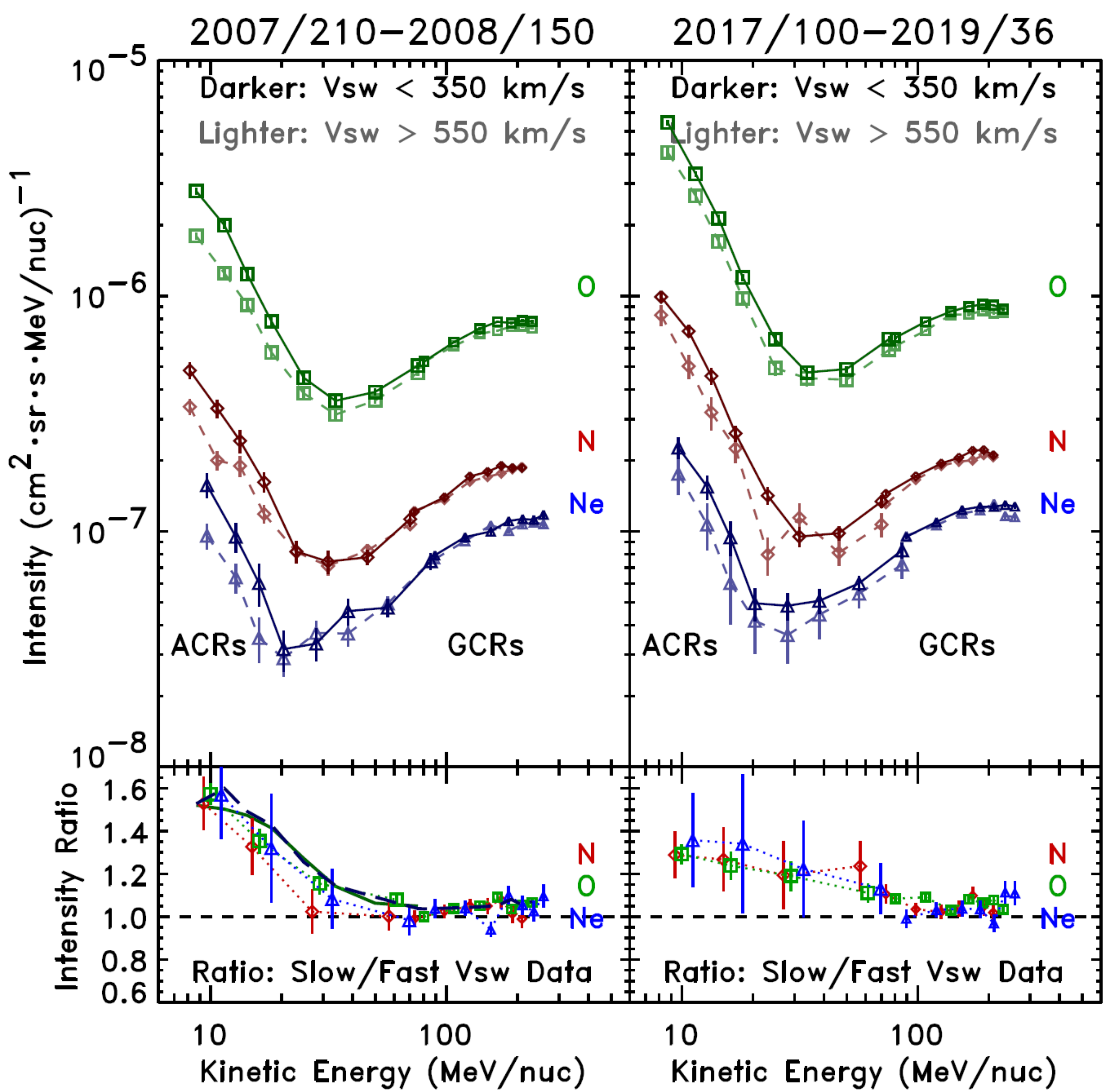




The amplitude of the GCR variations (their index with respect to Vsw) does not show much dependence on species (for C, N, O, Ne, Na, Mg, Al, Si, S, Ar, Ca, Fe, Ni) or rigidity within the CRIS energy interval.

The average index of
-0.076 +/- 0.004 corresponds to a peak-to-valley intensity variation of
5.4 +/- 0.3% for a factor of 2 change in the solar wind speed.

There is no significant difference in the GCR intensity variation with solar wind speed between the 2 solar minima.



Spectral differences between low solar wind speeds and high speeds:
GCR intensities are enhanced at low speeds by ~5%, while the lowest energy ***ACRs are enhanced ~50-60%*** ***in 2007-2008, and*** ***~30%*** ***in 2017-2019, with a strong energy dependence.***

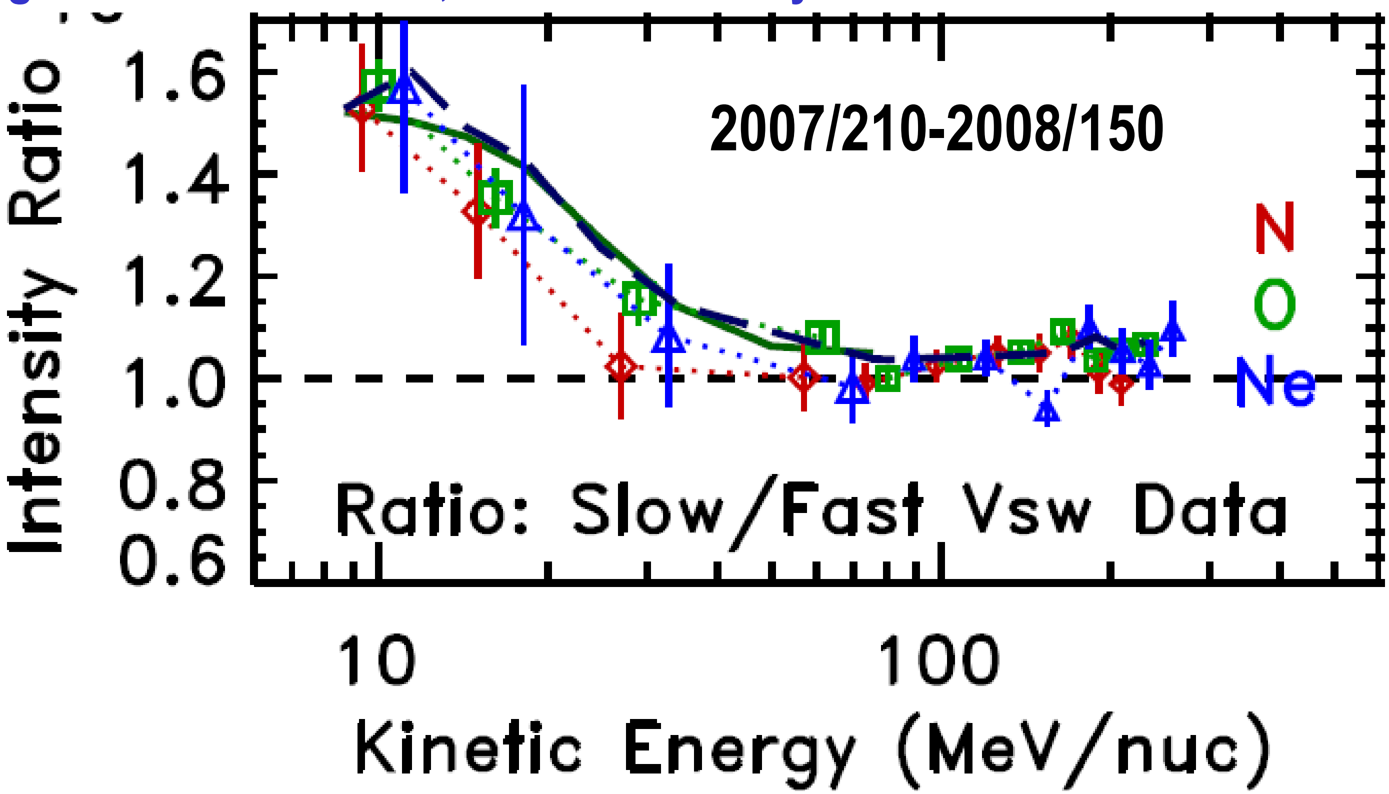
von Rosenvinge & Paizis *17th ICRC* **10**, 69 (1981) and Paizis *et al. JGR* **104** 28,241 (1999) describe the amplitude variation using force-field modulation:

$$\Delta c/c = -3C\Delta\varphi/\beta K(P),$$

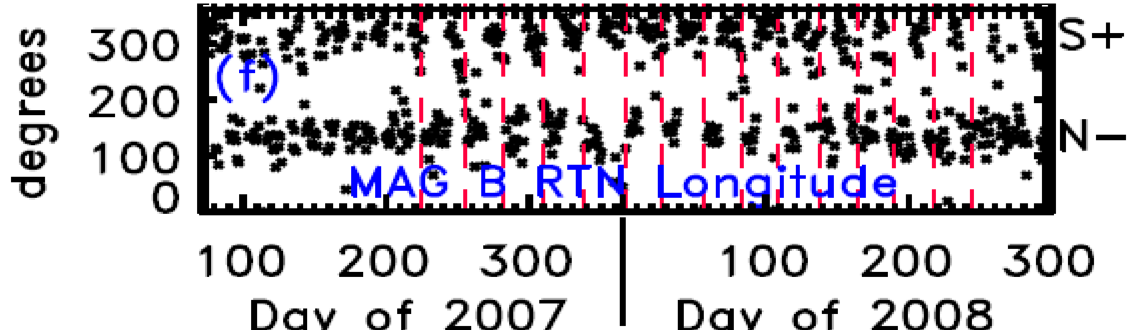
where c is the counting rate, φ the modulation parameter, β the particle speed, K the diffusion coefficient as a function of rigidity P (taken as $P^{0.5}$), and C the Compton-Getting factor, which for power law spectra in E with index γ is:

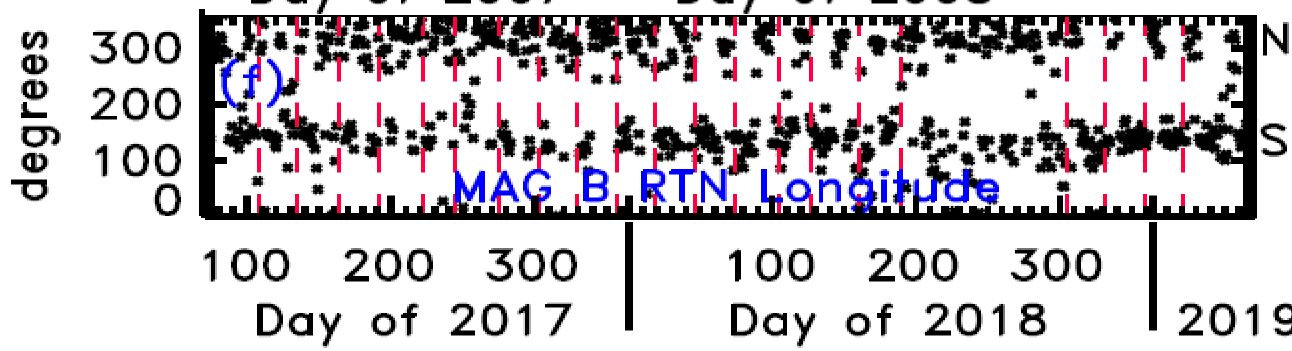
$C=(2-\alpha\gamma)/3$, where $\alpha=(E+2E_0)/(E+E_0)$, with E_0 the rest mass.

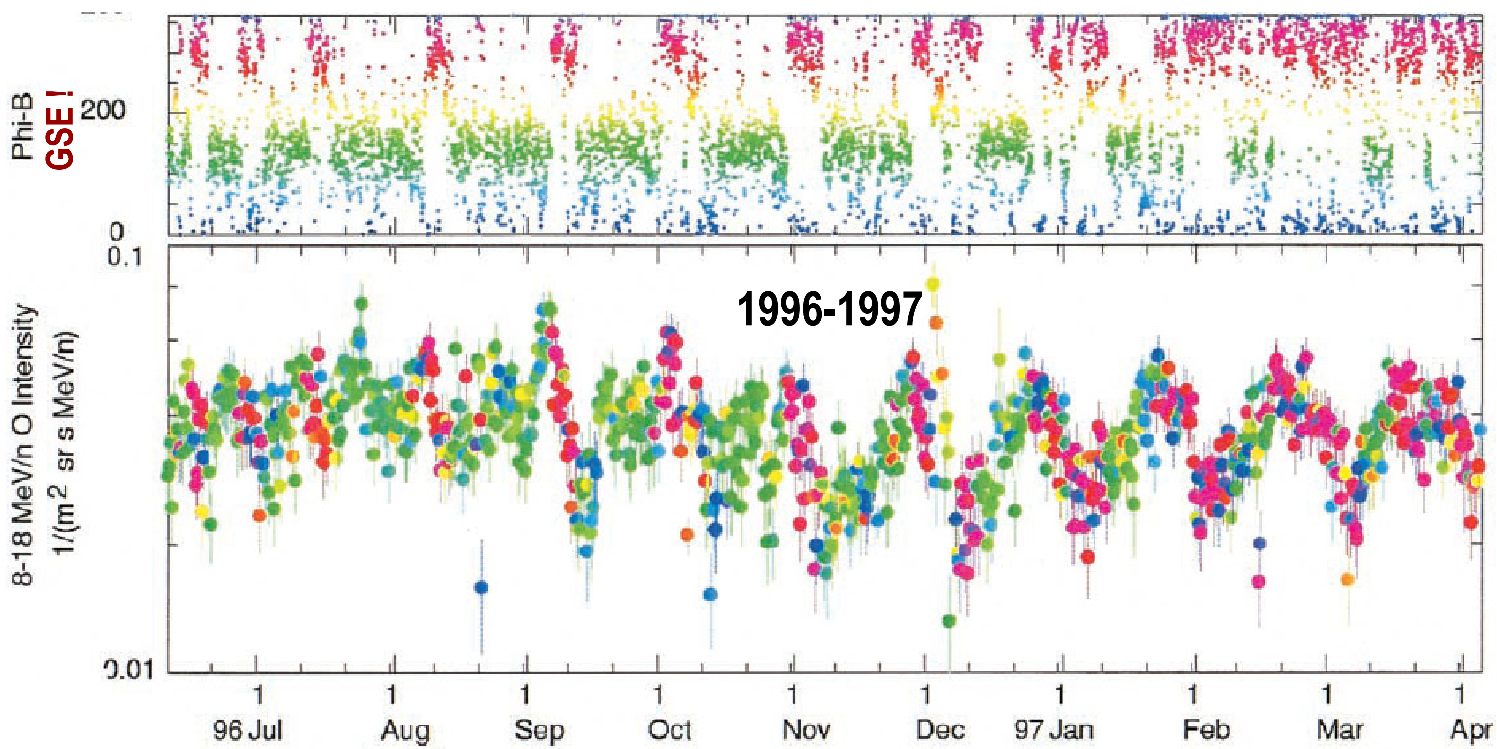
This formula gives the *dashed curve* below. Instead, just assuming an energy-independent amplitude of 55% for ACR O and 5% for GCR O and mixing by their relative abundances gives the *solid curve*, which is virtually identical.



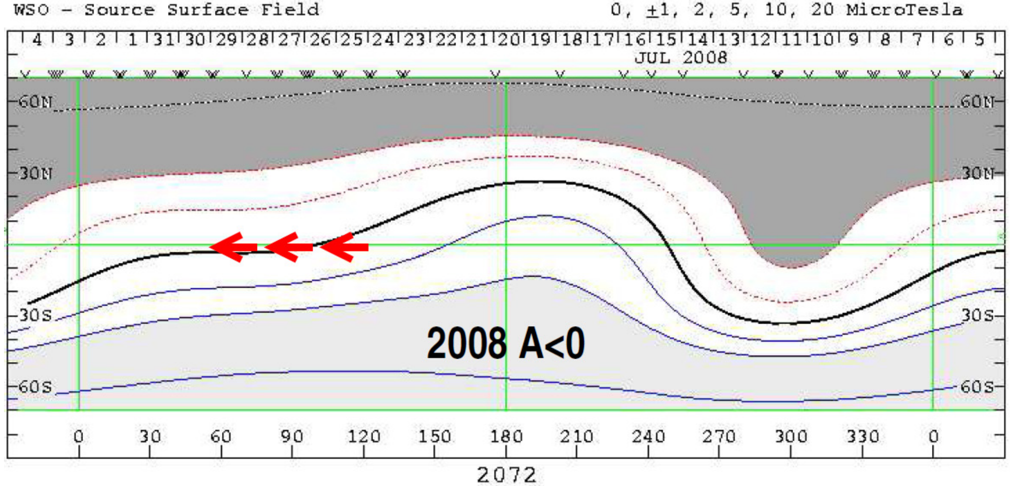
In 1996-1997, 2007-2008, and 2017-2018, cosmic ray intensity peaks occurred at outward-to-inward polarity HCS crossings (heliographic N to S during A>0, S to N during A<0). **But by 2019, this had changed to inward-to-outward.**

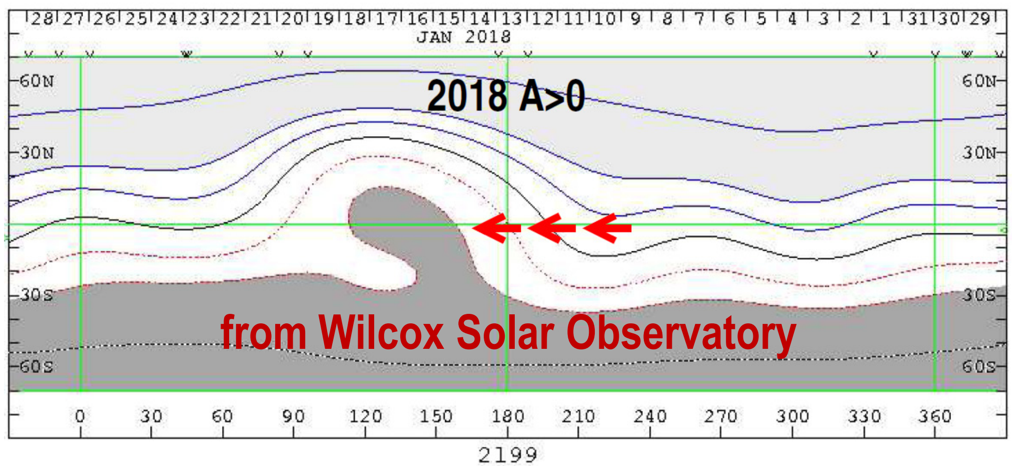




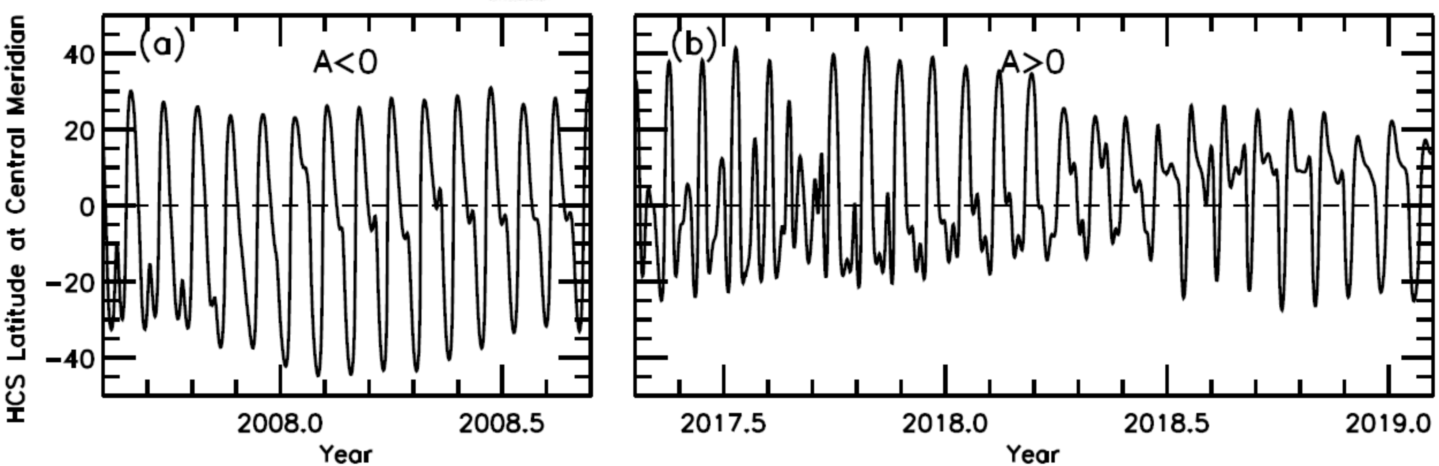


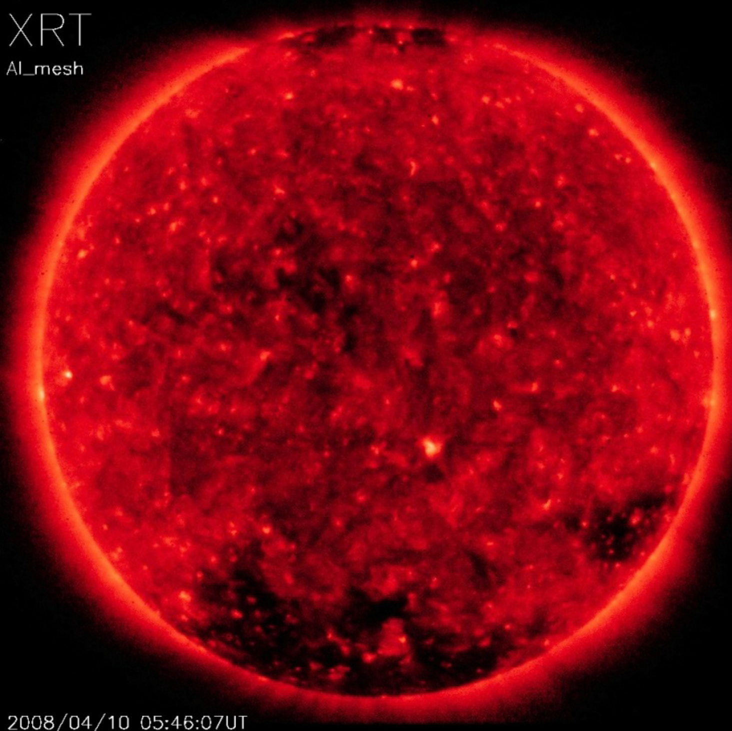
Reames & Ng, *ApJL* **563**, L179 (2001)





The 2 HCS crossings per rotation are often asymmetric, with one a rapid crossing and the other skimming along the sheet. Particles drift into the heliosphere along the HCS during A<0 cycles, and out during A>0. Peaks had occurred at the flatter, more gradual crossings during A<0 but at the more abrupt crossings during A>0. *But by early 2019 there's not much asymmetry in the ecliptic, so it's unclear if this pattern still persists.*





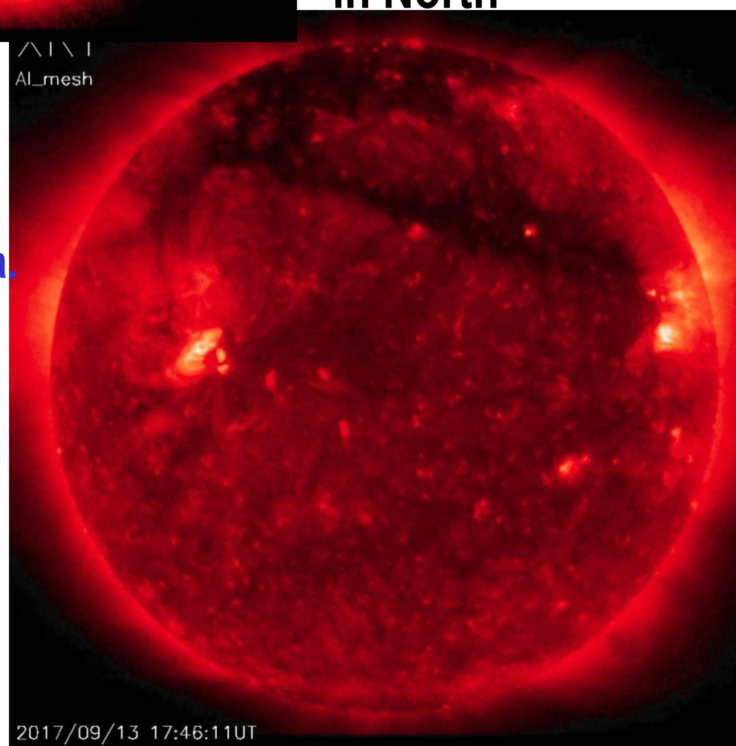
Which side of the HCS has the dominant coronal hole is probably the key factor in determining which HCS crossing leads to an increase in particle intensities:

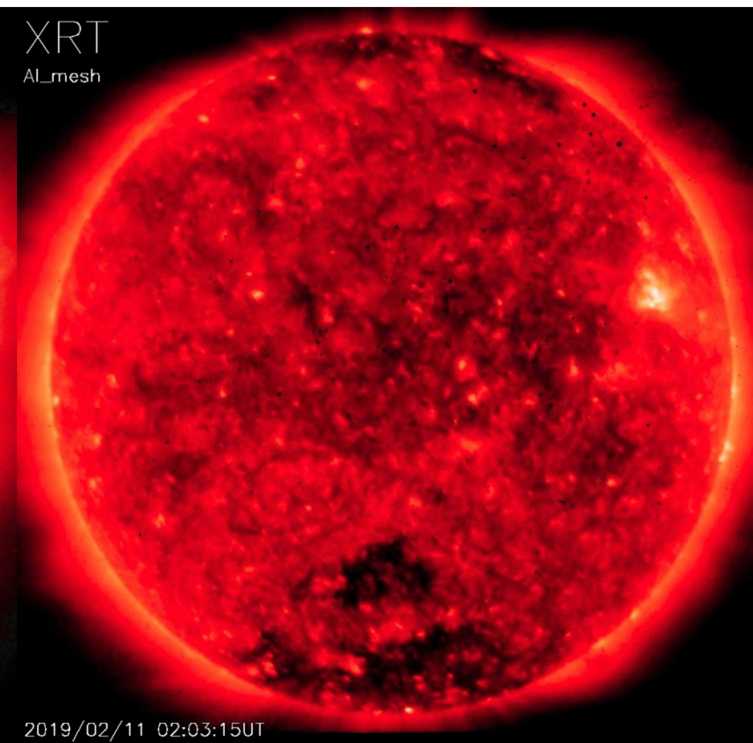
2008/04/10
High speed wind (low particle intensities)
in South

2017/09/13
High speed wind
(low particle intensities)
in North

2019/02/11
High speed wind
(low particle intensities)
in South

Hinode/XRT images
from
solar.physics.montana.
edu/HINODE/XRT





Summary

- **27-day variations in ACRs and GCRs in both 2007-2008 and 2017-2019:**
  - **were anti-correlated with solar wind speed (as a power law),**
  - **with larger amplitudes for ACRs than GCRs, and**
  - **little to no energy dependence in CRIS GCRs but large energy dependence for ACR species.**
- **Relative amplitudes of the ACRs and GCRs agree well with expectations from simple force-field modulation**
  - **ACR amplitudes seem to be less now than in 2007-2008, while GCR amplitudes are the same.**
- **Peaks are seen only at every second sector crossing:**
  - **Has been at outward-to-inward polarity HCS crossings for the last 3 solar minima,** until ~2019 when it became inward-to-outward polarity ➔ **polarity alone is not fundamentally important**
  - **The sector crossings are often asymmetric; “flat” crossings skimming the HCS had been favored during A<0 (when drift is inward along HCS), with peaks at abrupt crossings during A>0 (when drift is inward from high latitudes). But this pattern is no longer clear in recent data**
  - **Crossing the HCS to the side <u>without</u> the dominant coronal hole leads to particle increases, while the other crossing leads to decreases.**