Forecasting of geoeffectiveness and Cosmic Ray modulation induced by Corotating Interaction Regions

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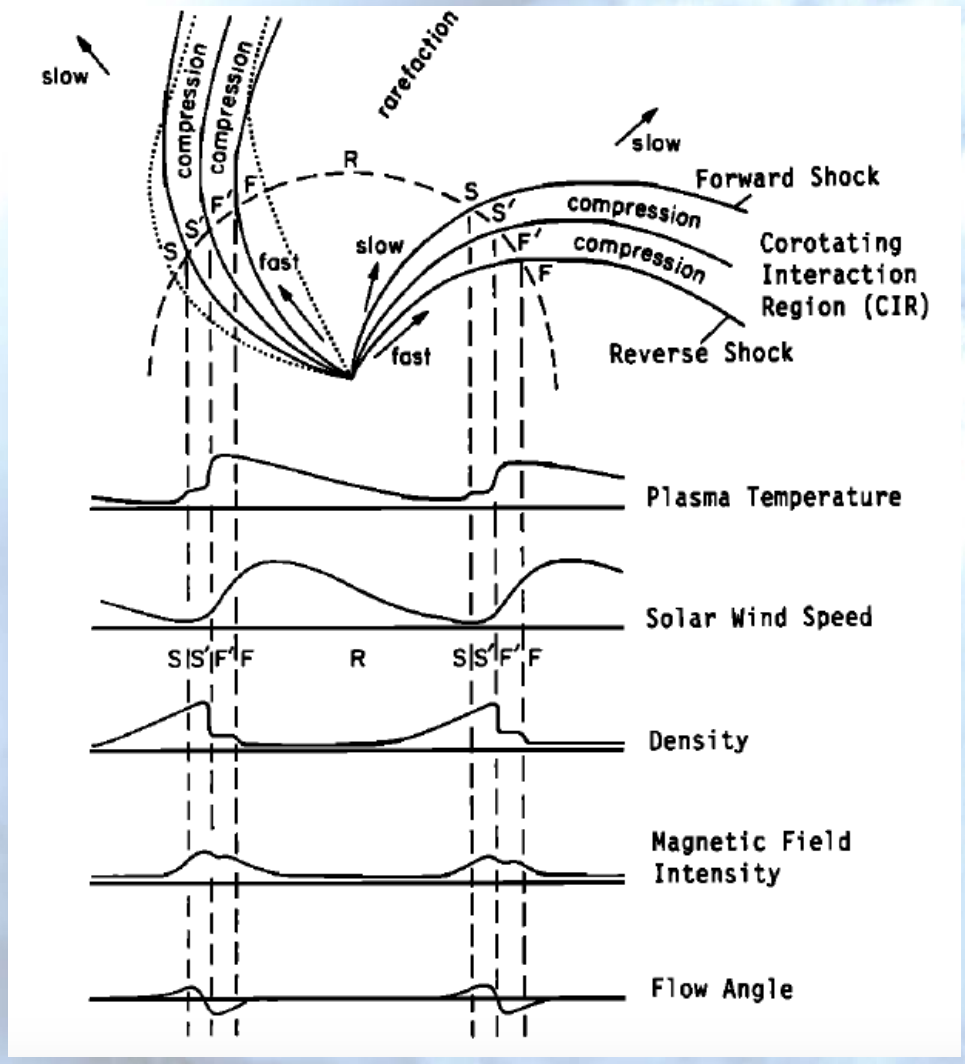
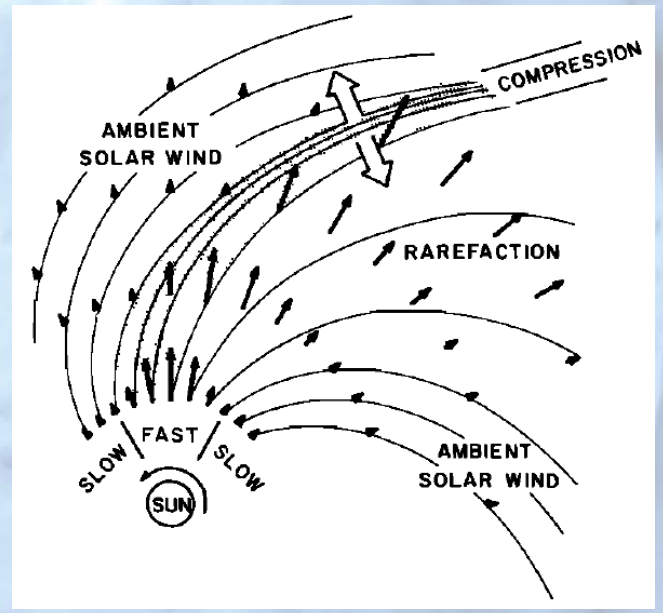
Corotating Interaction Regions (CIR)



Richardson, 1993

- compression regions formed from the interaction of high- and low-speed solar wind streams
- corotating with the Sun
- Major driver of solar-wind disturbances and geomagnetic storms during solar minimum (low CME activity)



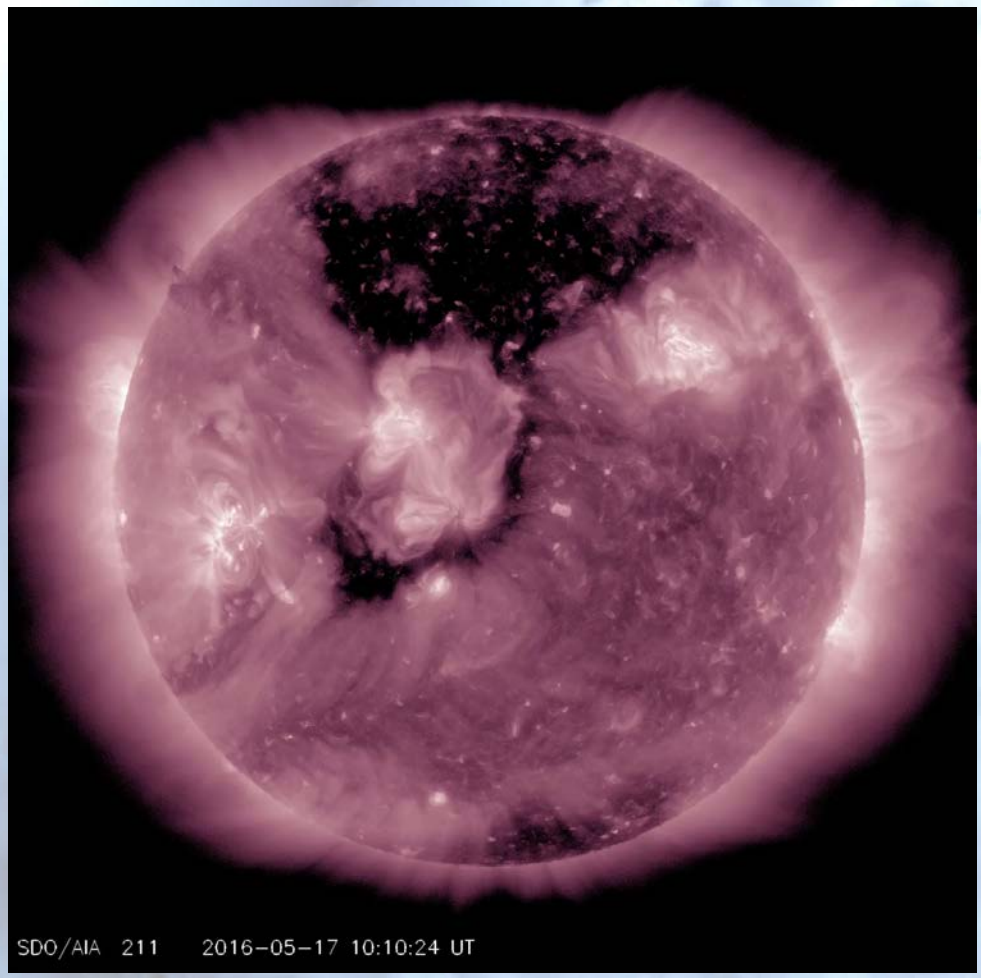
Pizzo, 1978

CIRs and geoeffectiveness

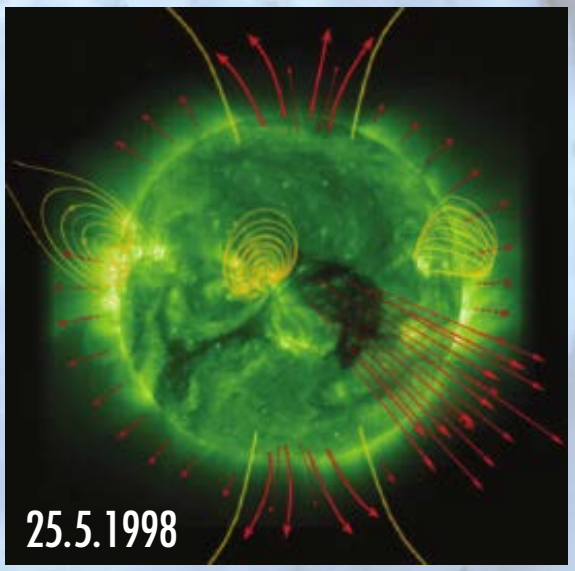
- Total impact of CIRs on geoeffectivity can be even larger or comparable to ICMEs - long-lasting and permanent contribution to geomagnetic activity throughout the whole solar cycle (Tsurutani et al., 1995; Vennerstroem, 2001; Tsurutani et al., 2006)
- CIRs can be source of geomagnetic activity for about **70%** of time in **solar min** and about **30%** in **solar max** (1972 - 1986). For comparison CME-related structures contribute 50% in solar max and <10% outside the solar max (Richardson et al., 2000)
- About **33%** of CIRs (1964-2003) at Earth are followed with moderate or intense geomagnetic disturbances, Dst < 50nT (Alves et al., 2006)
- About **47%** CIR in solar cycle 23 (1996-2005) produced storms with Dst < 50nT (Zhang et al., 2008)
- 2-5% of CIRs can occasionally alone produce major geomagnetic storms with Dst < 100nT (Alves et al., 2006; Zhang et al., 2008)
- Geomagnetic activity is most influenced by the **southward component of the IMF, Bs** (Gonzalez et al., 1994; Tsurutani and Gonzalez, 1995)

Coronal Holes (CH)

Large CH, May 17 – 19, 2016



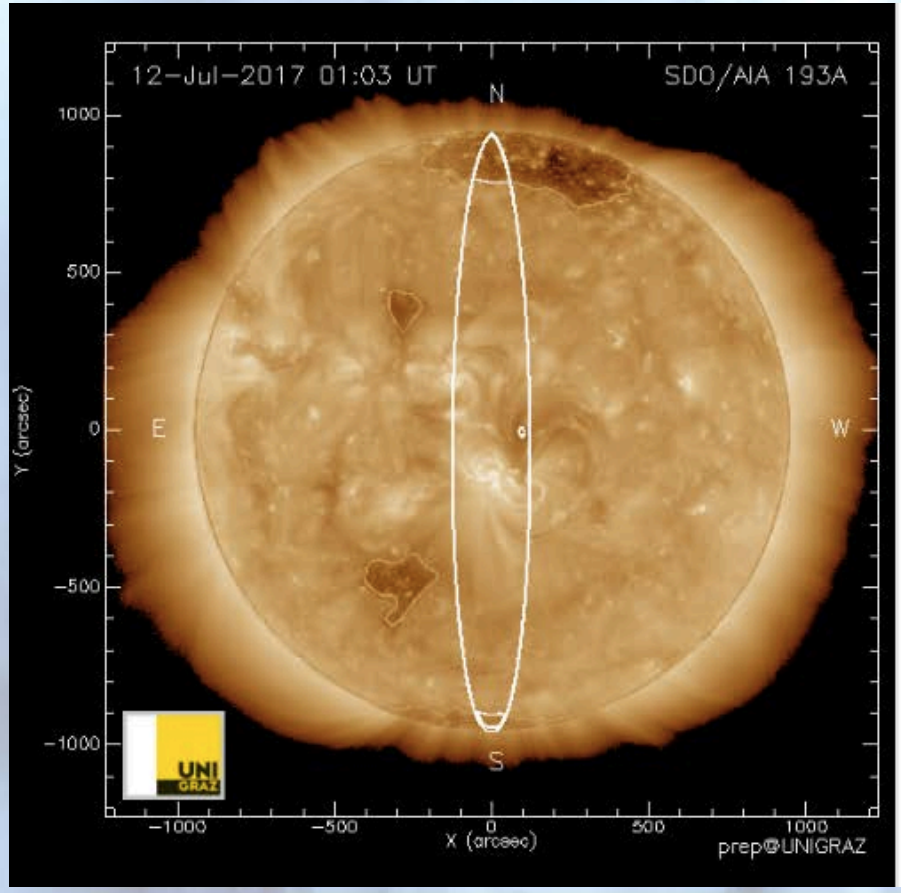
- source regions of the high-speed solar wind
- connected with open magnetic field form the Sun
- visible as dark regions in EUV or X-ray observations of the solar corona

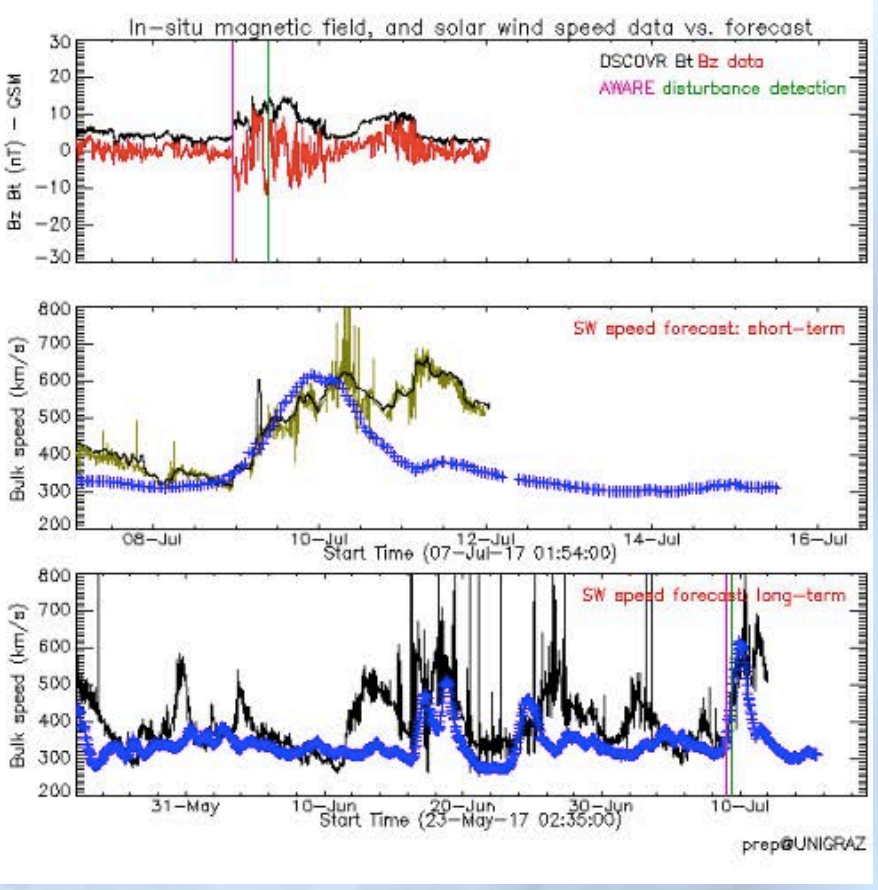


Coronal holes and solar wind

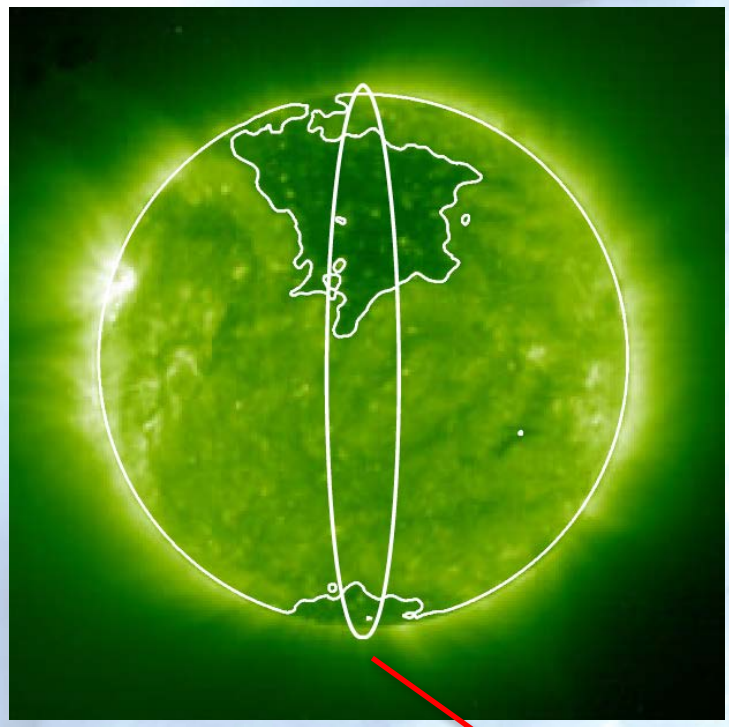
Forecasting solar wind high-speed streams (ESWF)
http://swe.uni-graz.at/index.php/services/solar-wind-forecast

- based on an empirical relation between CH and high speed streams measured at Earth (Vršnak et al. 2007)
- CH areas are extracted from EUV images (Krista and Gallagher, 2009; Rotter et al., 2012; Reiss et al., 2015)

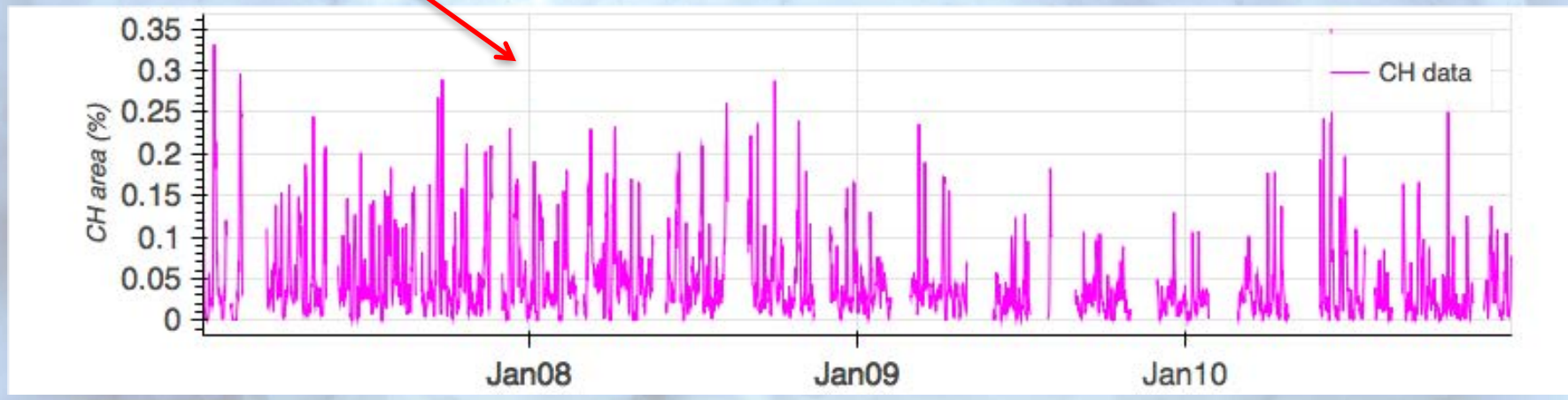




CH area data

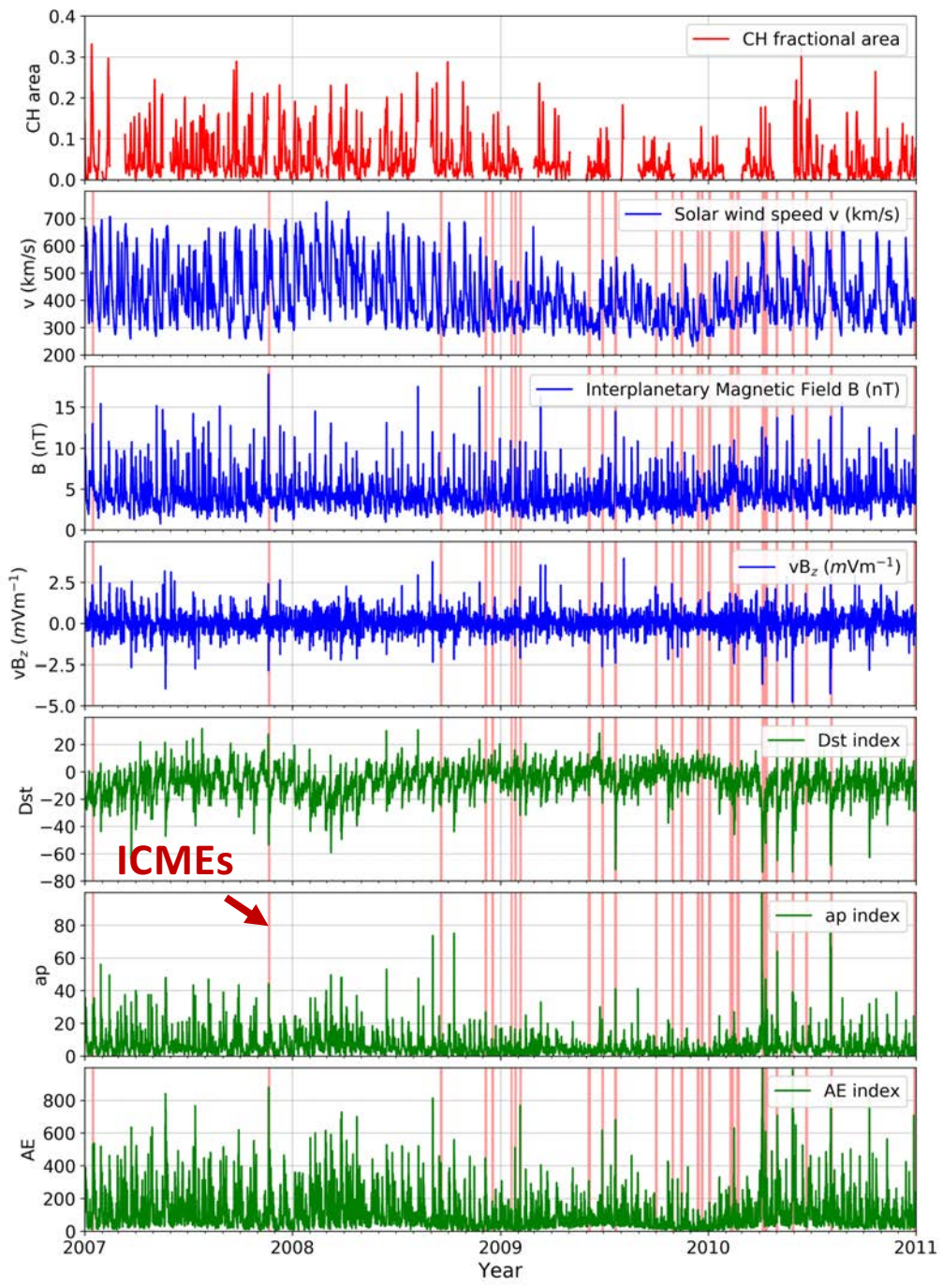


- extracted with SOHO EIT 195 Å images
- CHs can be identified with intensity-based thresholding technique (Rotter et al., 2012, Reiss et al. 2016)
- fractional coronal hole area is derived from a central meridional slice (±7.5°) corresponding to the solar rotation within aprox. 1 day
- period of CH data: 1.1.2007 – 31.12.2010
- 4 measurements per day, 23% missing data



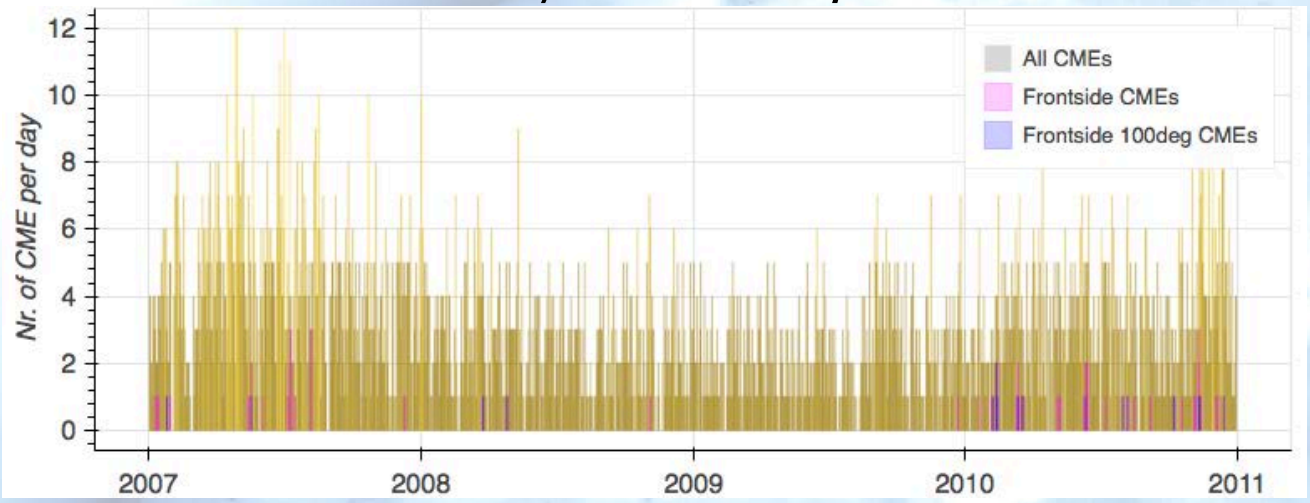
CH fractional area, solar wind parameters (v, B, vB_z) and geomagnetic indices (Dst, ap, AE) during period 2007-2011

Dst index - strength of magnetic disturbance at the dipole equator on the Earth's surface (ring current).
ap index - level of the middle latitude magnetic activity during the periods of 3h (derived from Kp).
AE index - measure of a global auroral zone magnetic or substorm activity produced by enhanced ionospheric currents flowing below and within the auroral oval (polar electrojet)

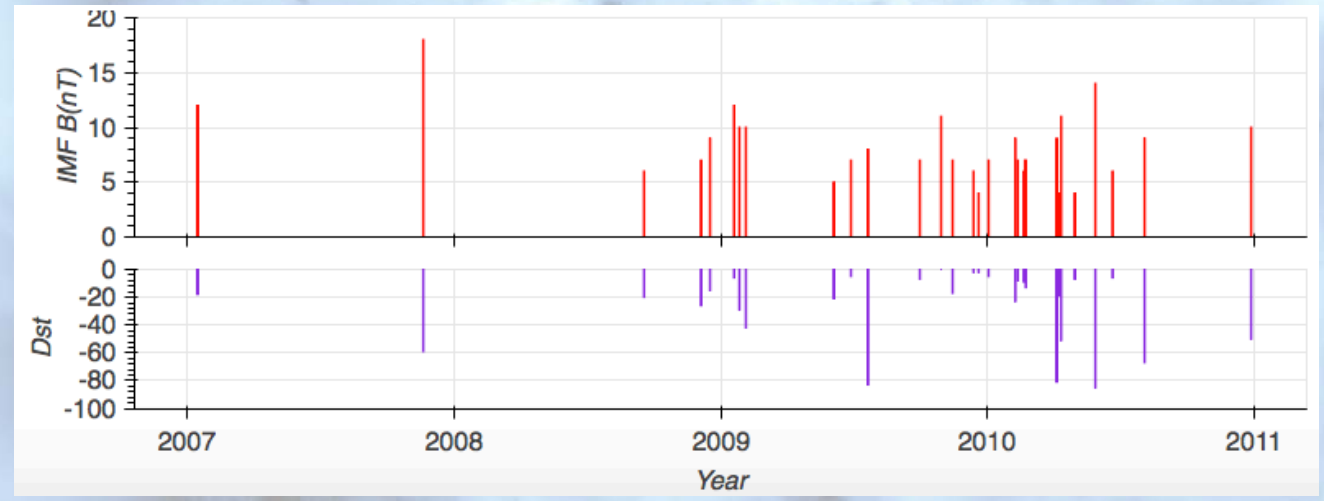


CMEs / ICMEs (2007 – 2011)

SOHO/LASCO CME daily data



ICME list (Richardson & Cane, 2010)



30 ICMEs during 2007 – 2011 period based on ICME list from Richardson & Cane, 2010

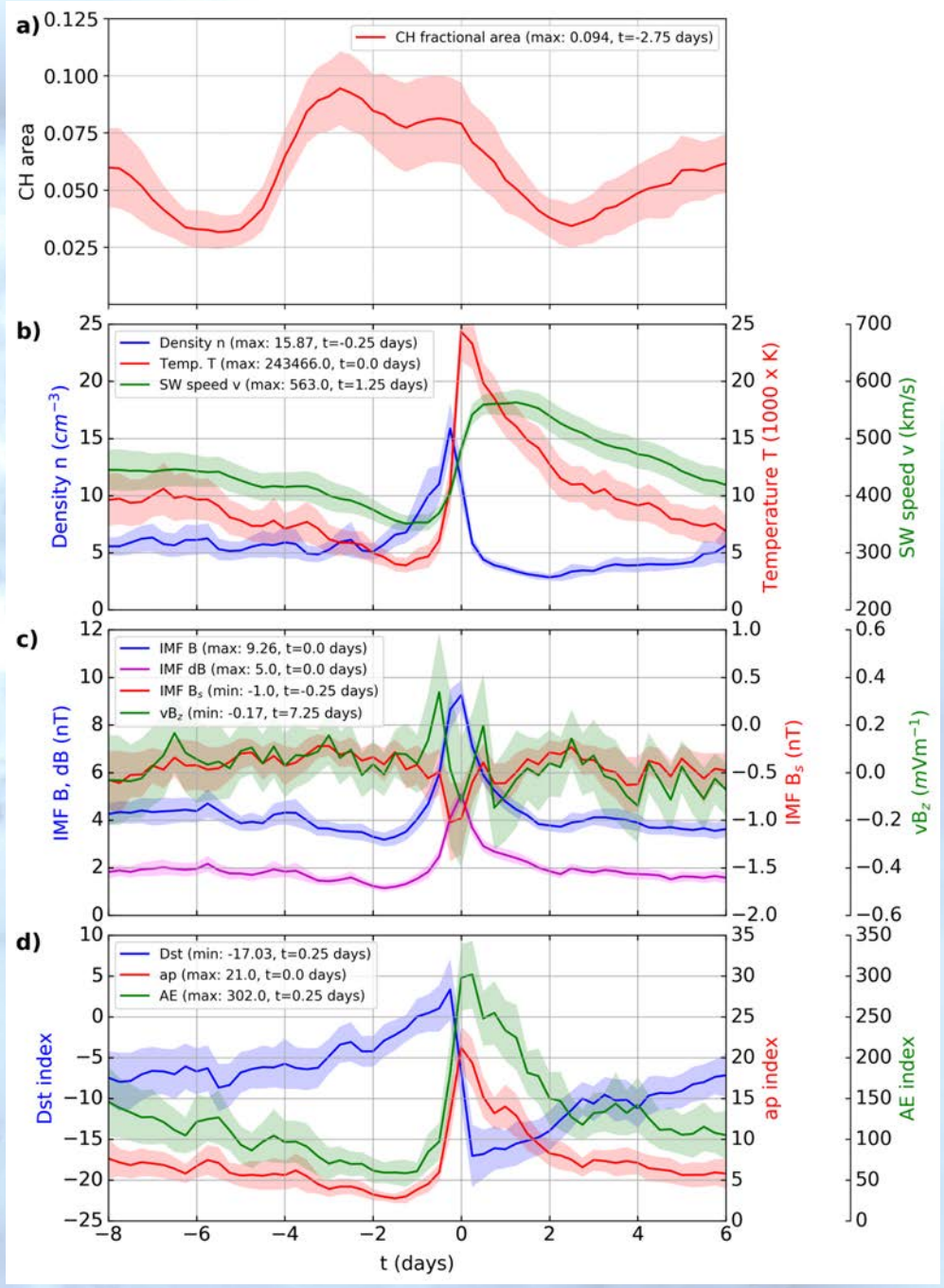
ICMEs removal

- 12h before ICME event removed
- 72h after ICME event removed
- in total 9.2% data excluded (101 days)

Superposed epoch analysis (SEA) during period 2007 - 2010

- 52 CIR events selected, SIR list from Jian et al. 2011
- All events centered around key date (t = 0) corresponding to arrival of stream interface

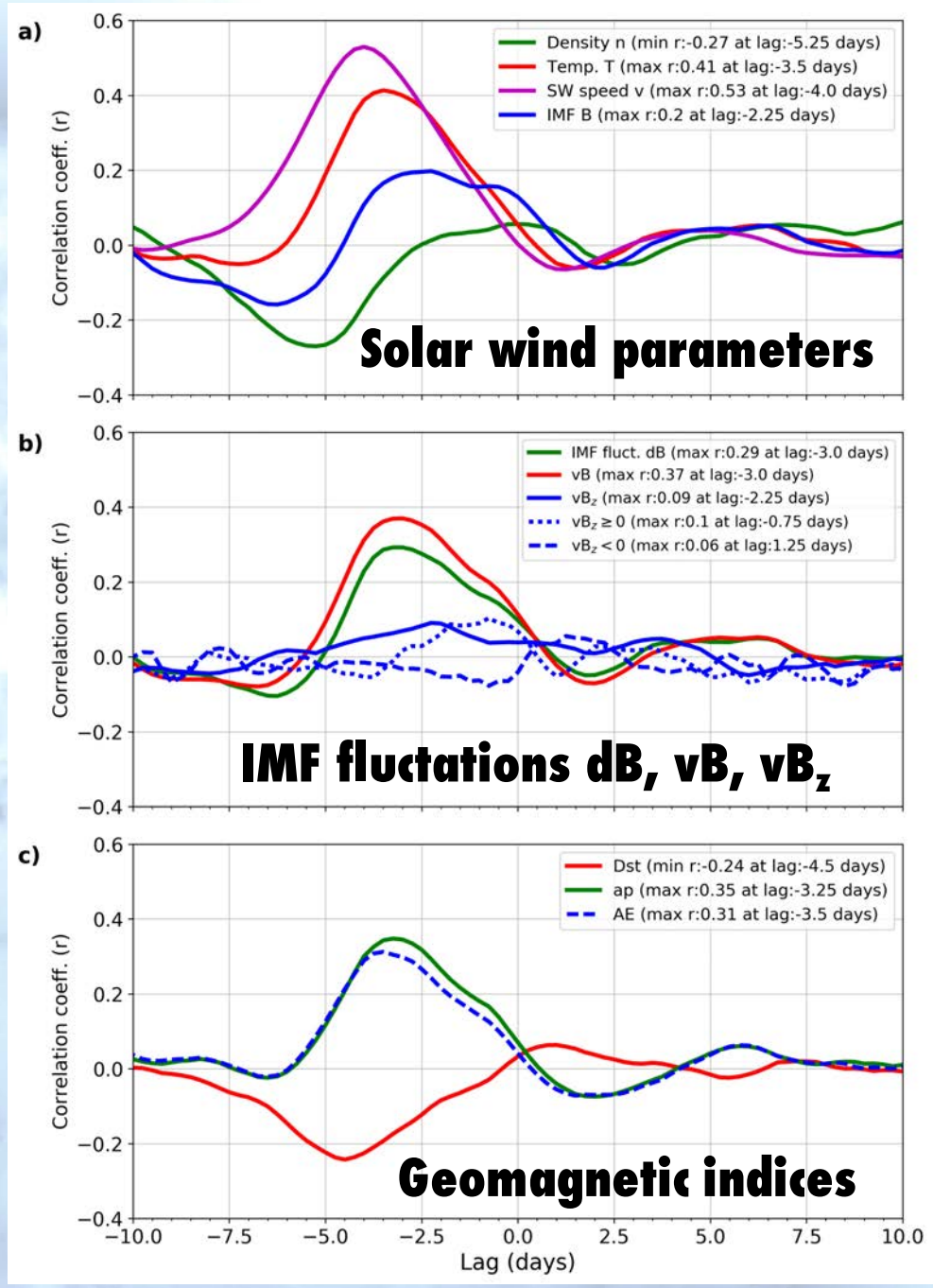
- B_z and vB_z as well the enhanced dB between t = -0.5d and t = 2d indicate Alfven wave activity
- ap index shows somewhat faster recovery than AE - more sensitive to smaller magnetic field fluctuations or Alfven wave activity



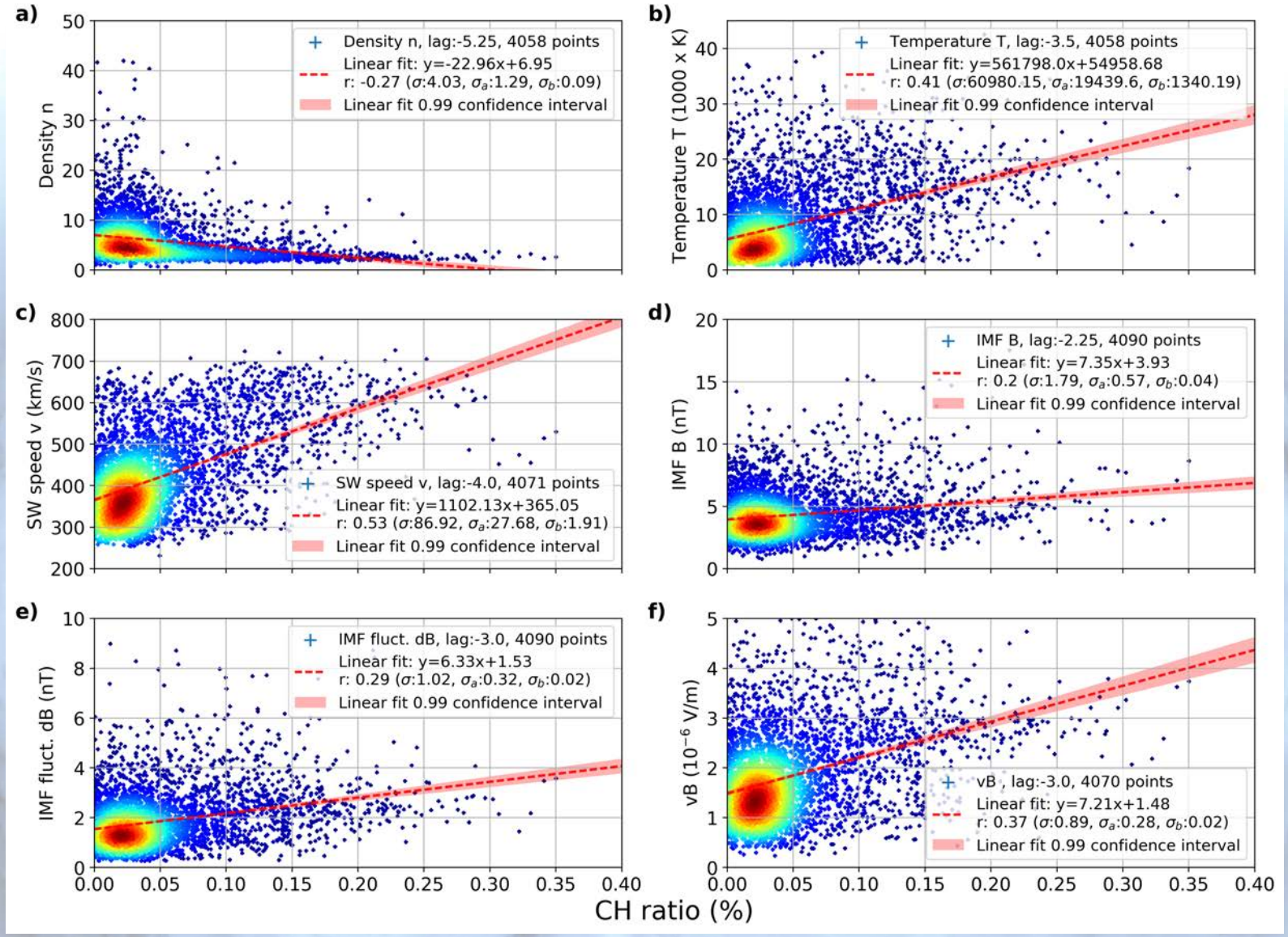
Cross-correlation analysis

- Best correlation with solar wind speed, v (r=0.53 at lag=-4d)
- IMF B (r=0.2 at lag=-2.25d), dB (r=0.29 at lag=-3d) and vB (r=0.37 at lag=-3d) show better correlation
- Convection electric field vB_z (r=0.09) shows no correlation with CH

- ap index (r=0.35 at lag=-3.25d)
- AE index (r=0.31 at lag=-3.5d)
- Dst index (r=-0.24 at lag=-4.5d)



CH ratio and solar wind parameters (n, T, v, B, dB, vB)

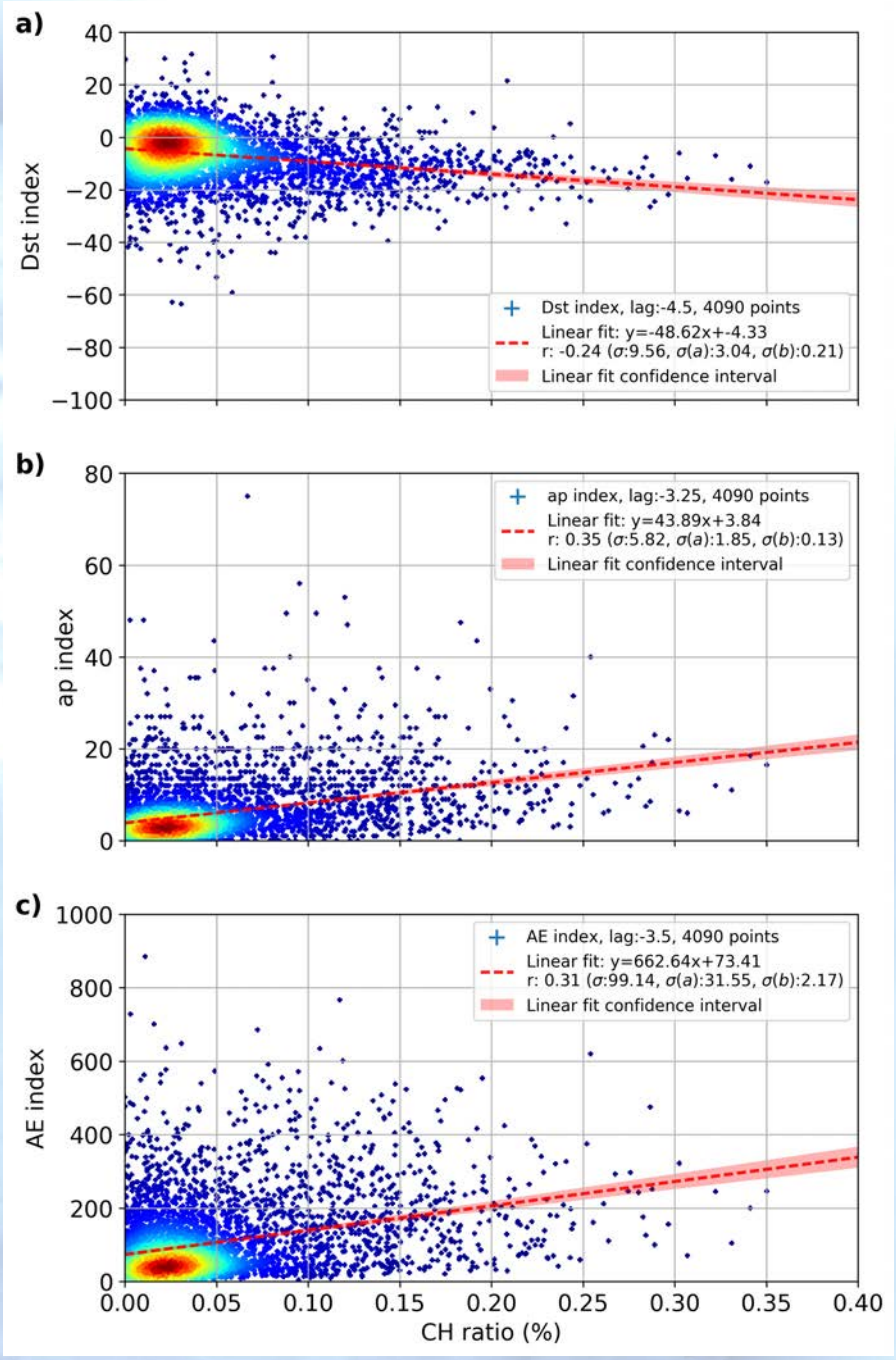


CH ratio and geomagnetic indices (Dst, ap, AE)

- Best correlation **ap index** (r=0.35 at lag=-3.25d), then **AE index** (r=0.31 at lag=-3.5d) **Dst index** (r=-0.24 at lag=-4.5d)

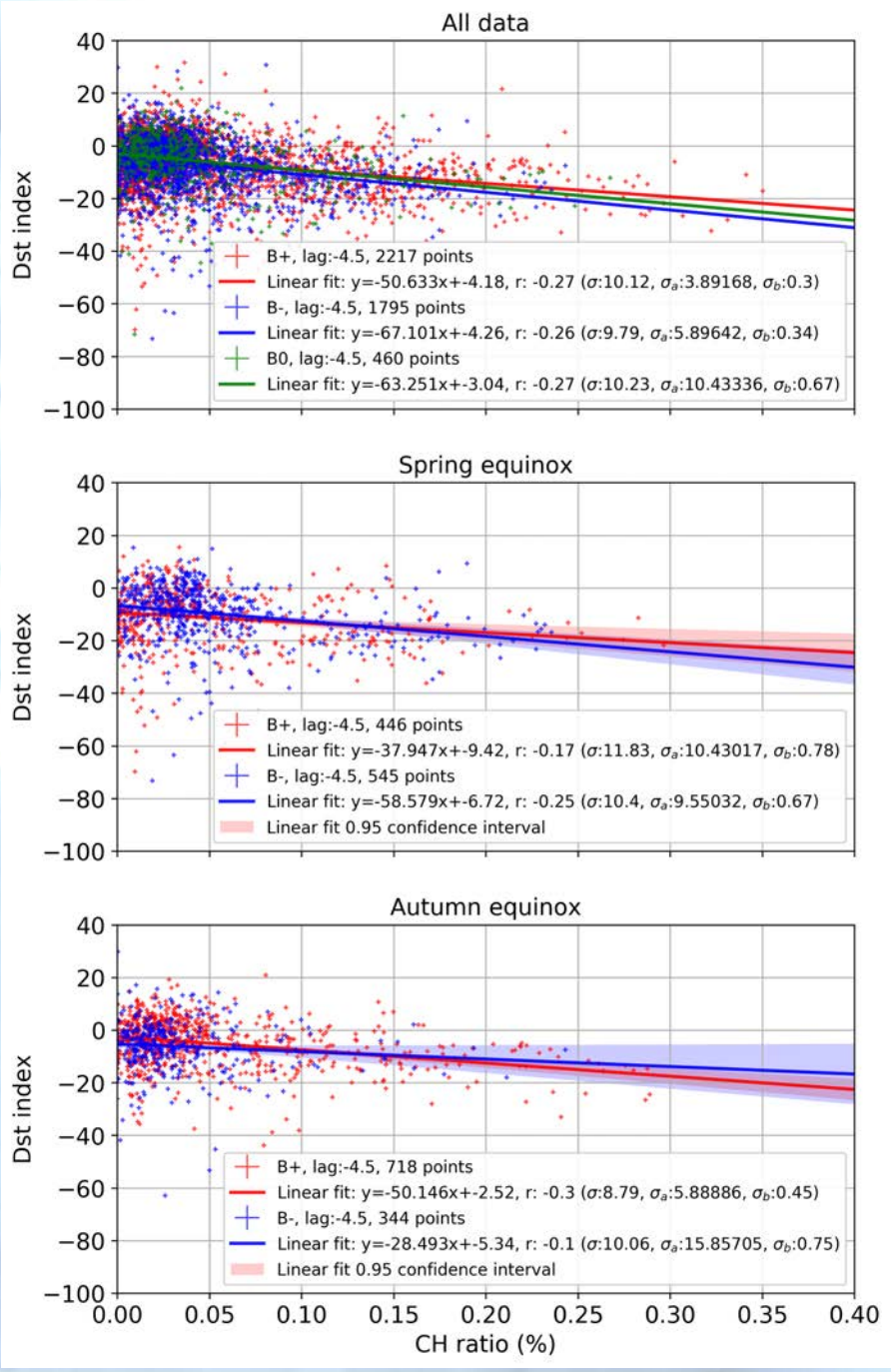
- Geomagnetic activity determined by convection electric field (E_y=-v x B_s)
- SW speed **v** relates very good to CH area, however $\mathbf{B_z}$ doesn't show good relation to CH
- v ranges 250-750 km/s (about 3x)
- Bz ranges 0-10 nT (5-10x)

Major problem: forecast accuracy is limited trough B_z



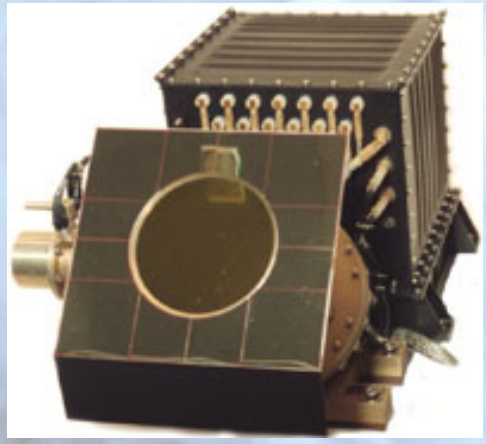
Semiannual variation (Russel-McPherron effect)

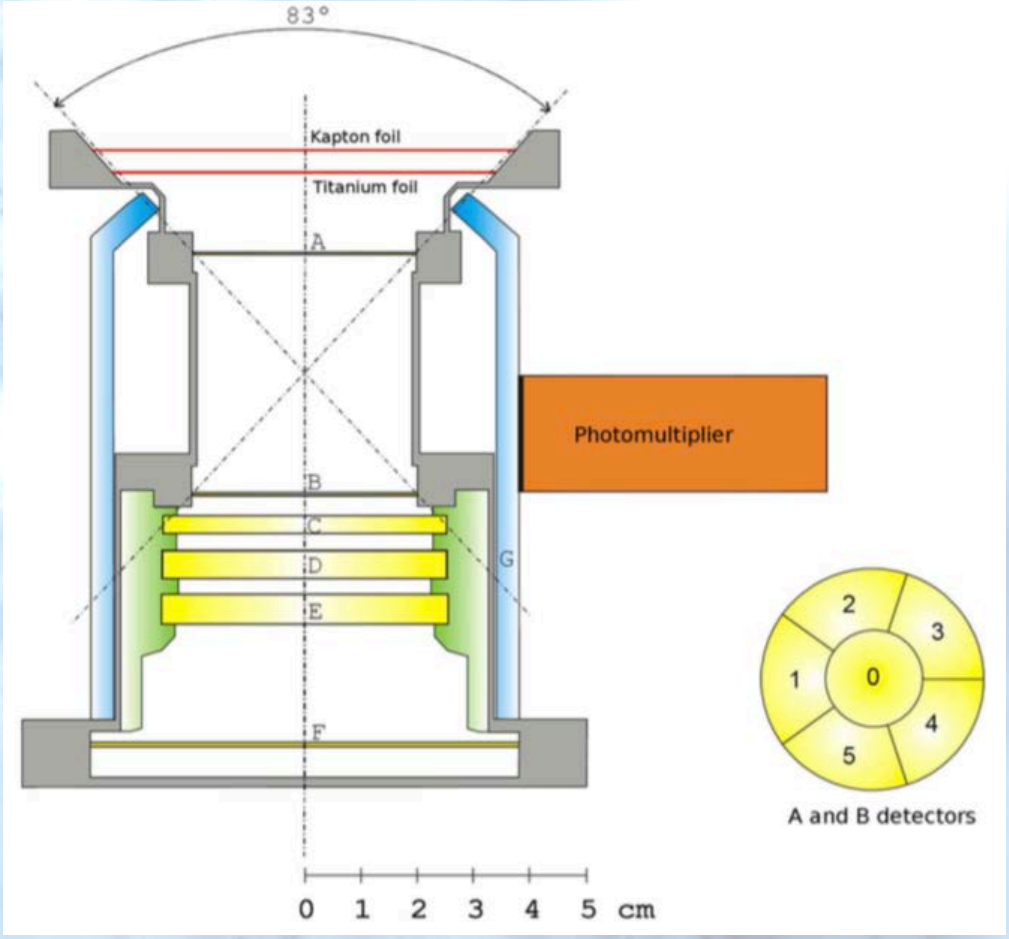
- dependence of geoeffectivity on different seasons (Russell and McPherron, 1973)
- in the period around the spring equinox the effect of negative polarity CHs on Dst is increased and positive polarity CHs is decreased
- In the period around the autumn equinox the situation reverses



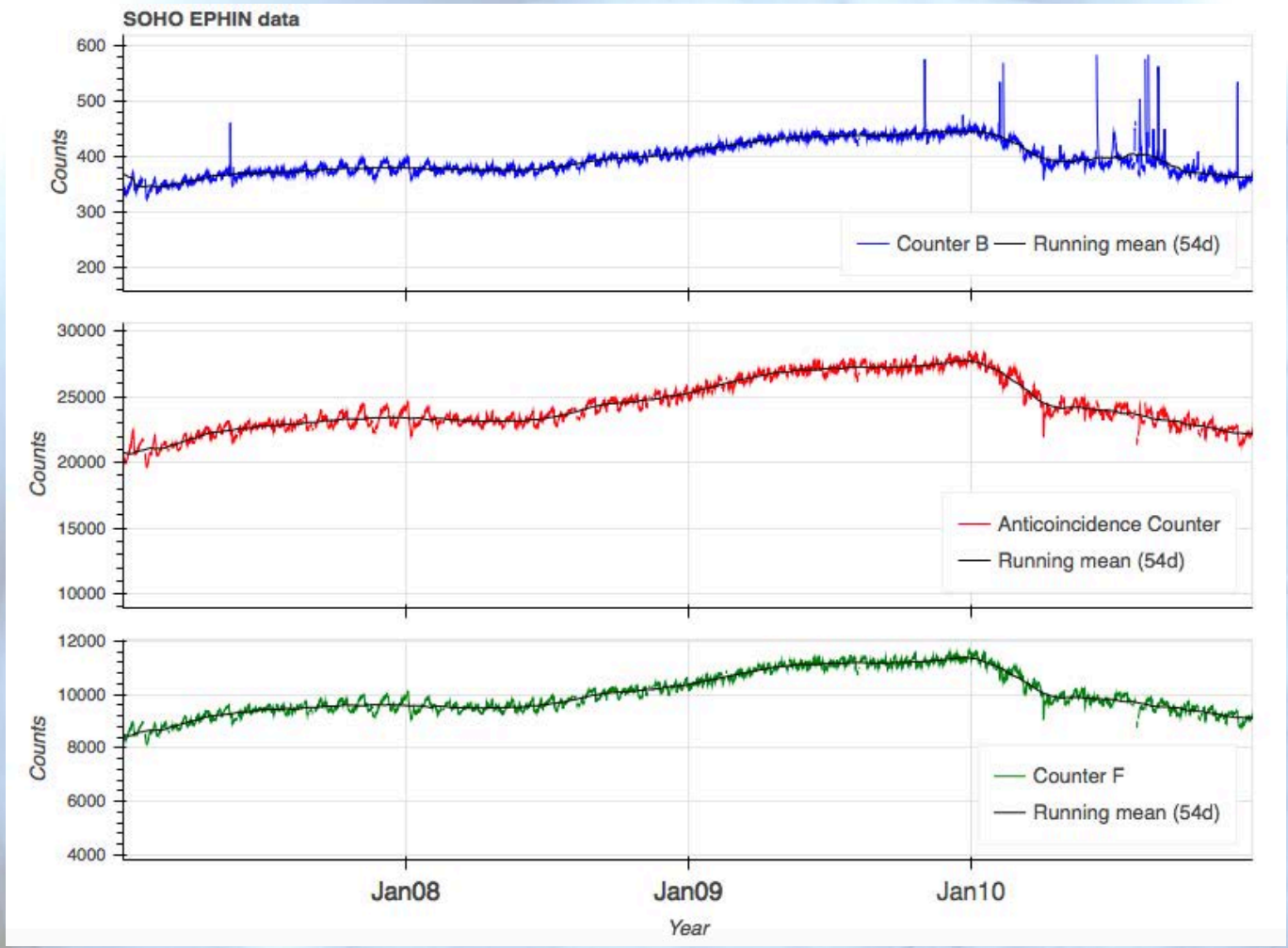
SOHO EPHIN

- Electron Proton Helium Instrument (EPHIN)
- onboard SOHO spacecraft
- data available from December 07 1995
- consists of several semiconductor detectors in layers (A-F) and a scintillation detector, operated in anticoincidence





SOHO EPHIN data



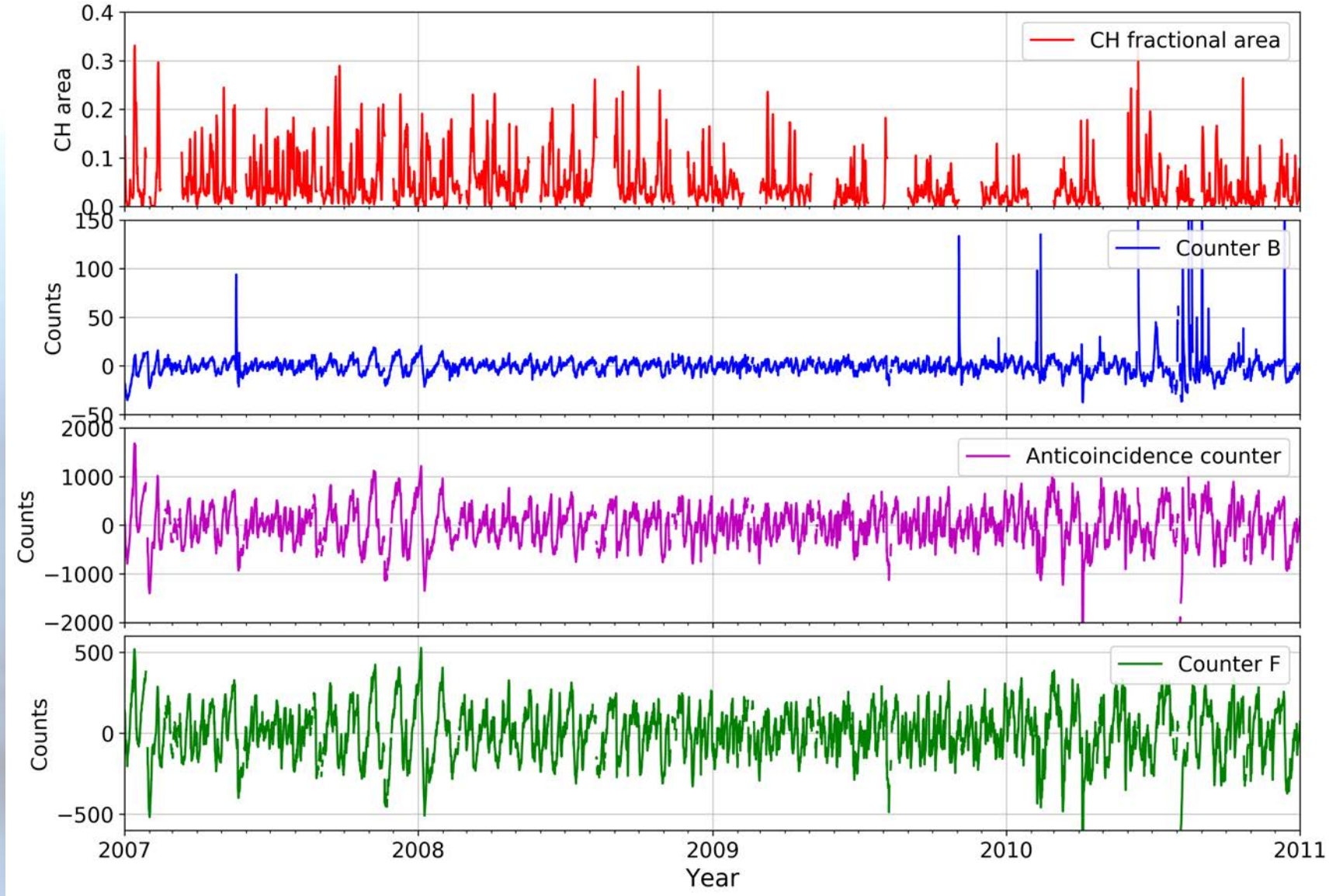
Counter B
> 4 MeV/n

Anticoincidence Counter

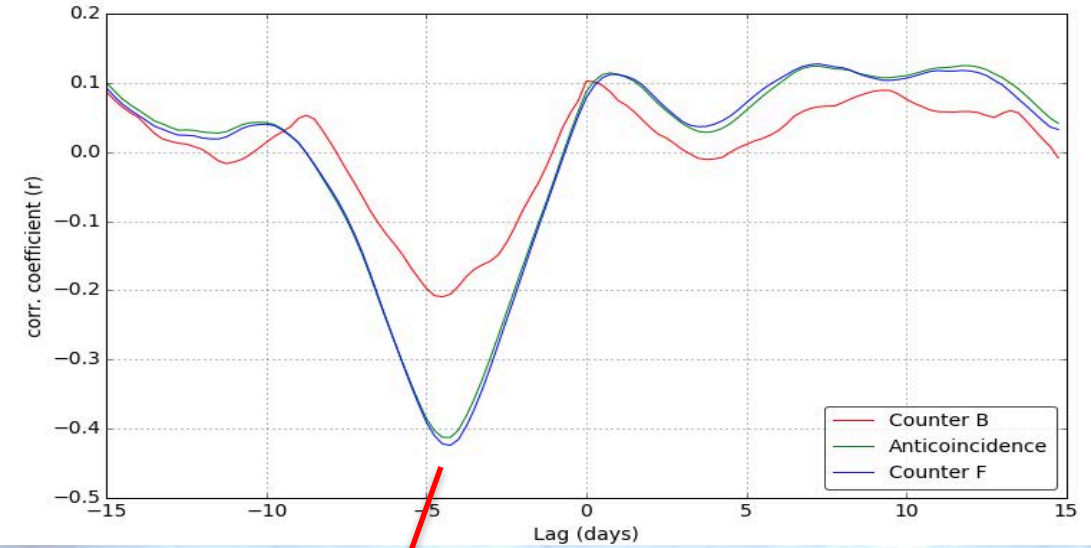
Counter F
> 50 MeV/n

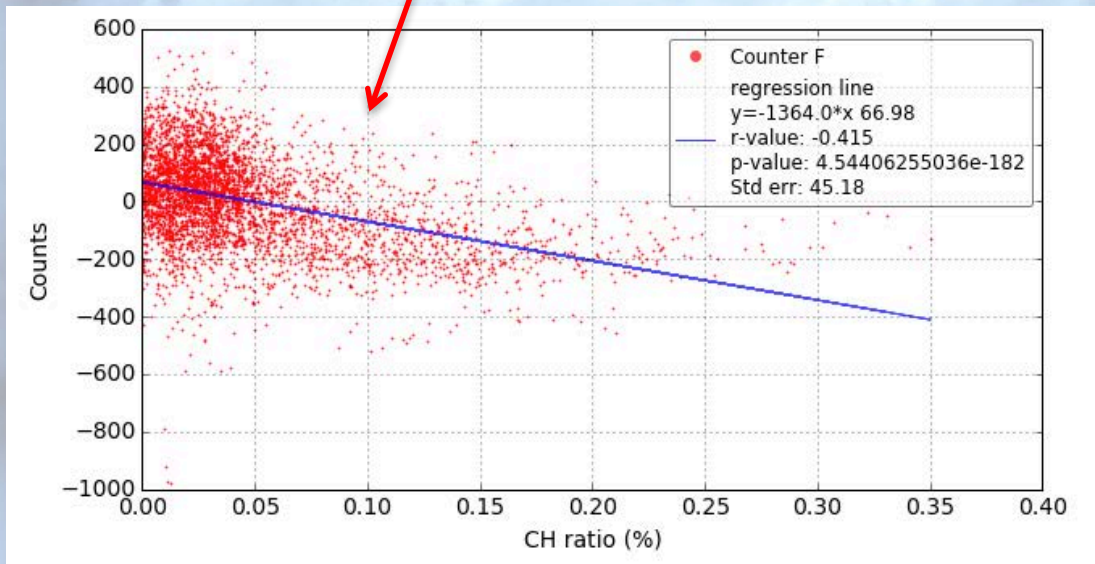
- interpolation of small gaps in the data (up to 18h)
- anomalies are calculated subtracting the running mean (54 days)

CH and CR flux, EPHIN (2007 – 2011)



CH area and CR flux (EPHIN)

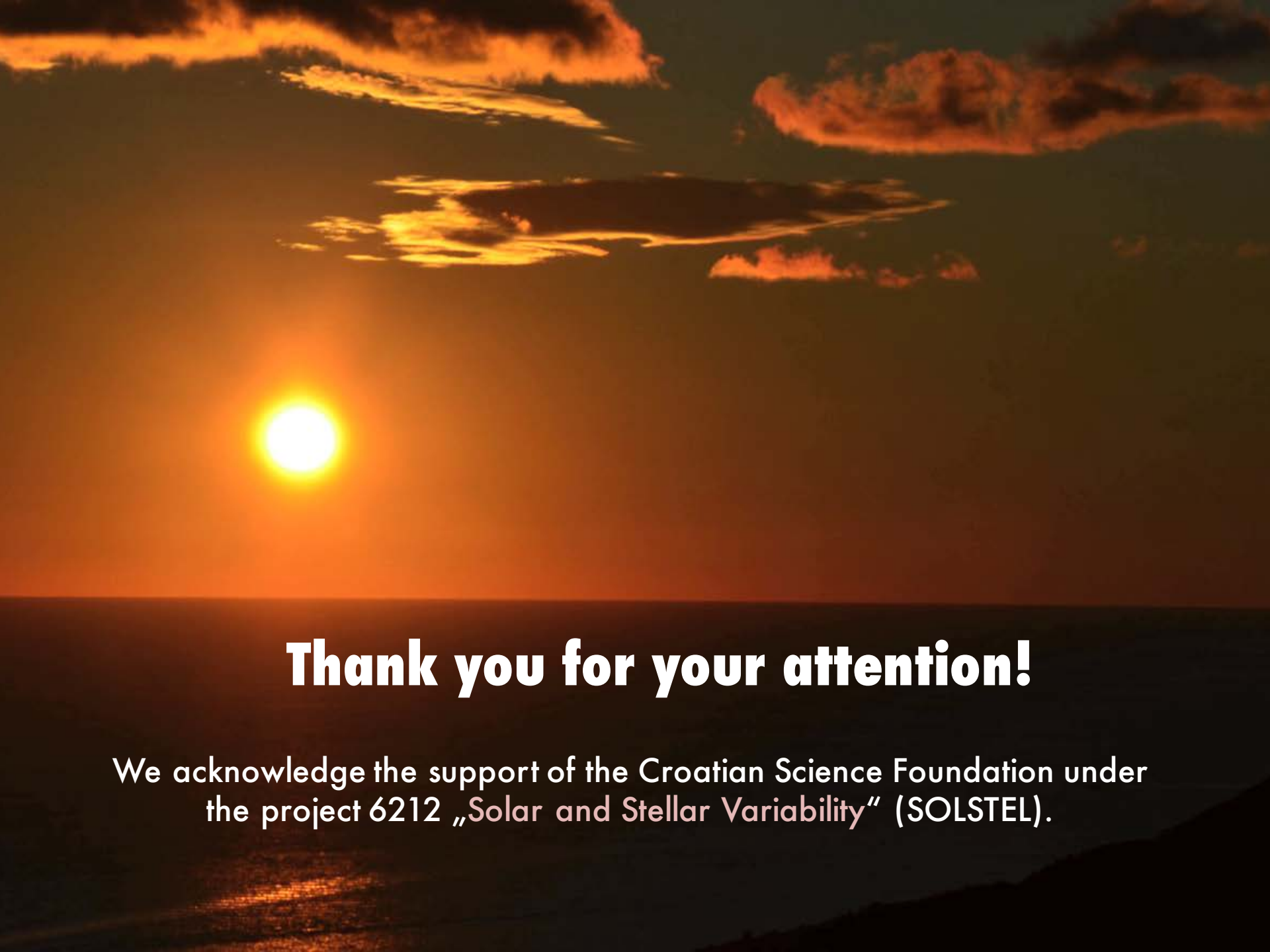




- Correlation with lag 4417 points (1104 days)
- Counter B: r = -0.23 (lag -4.75 days)
- Anticoincidence Counter: r = -0.40 (lag -4.50 days)
- Counter F: r = -0.42 (lag -4.5 days)

Conclusions

- Opportunity to forecast 3-4 days in advance a geoeffectiveness of CIRs as well as their effect on the cosmic ray flux during the solar minimum in the absence of ICMEs
- ap and AE indexes show good relationship to CH area (r=0.35 at lag=-3.25d, r=0.31 at lag=-3.5d) and Dst has slightly lower correlation coefficient (r=-0.24 at lag=-4.5d)
- Forecast limitation is unknown B_z that doesn't relate to CH
- Cosmic ray flux and CH area show also good correlation (r=0.4 at lag=4.5 d)
- Better forecast could be obtained by including the CH polarity data



Thank you for your attention!

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