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Abrupt shrinking of solar corona in late 1990s (and related changes in solar magnetic structure)

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Background: Coronal magnetic field and PFSS model

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- Coronal magnetic field defines the solar wind and heliospheric magnetic field structure.
- Therefore coronal field is highly important for space weather and space climate studies.
- Coronal magnetic field has not been measured over long time intervals. Need modeling!
- We use the PFSS model, which assumes current–free corona and radial magnetic field at the source surface.
  - Source surface radius r_{ss} is the only free parameter of the PFSS model.
- Field lines reaching the source surface radius are open and continue into the heliosphere
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  => **The smaller the r_{ss} is, the larger the open flux is.**

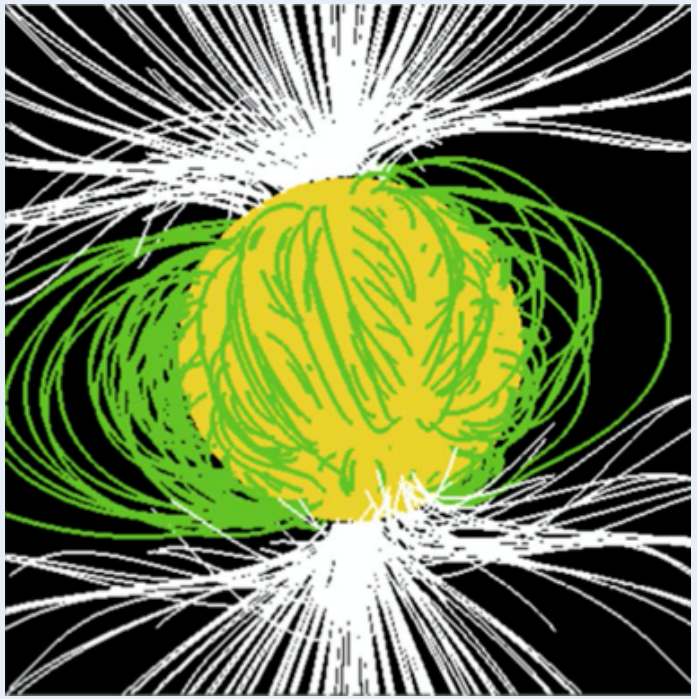
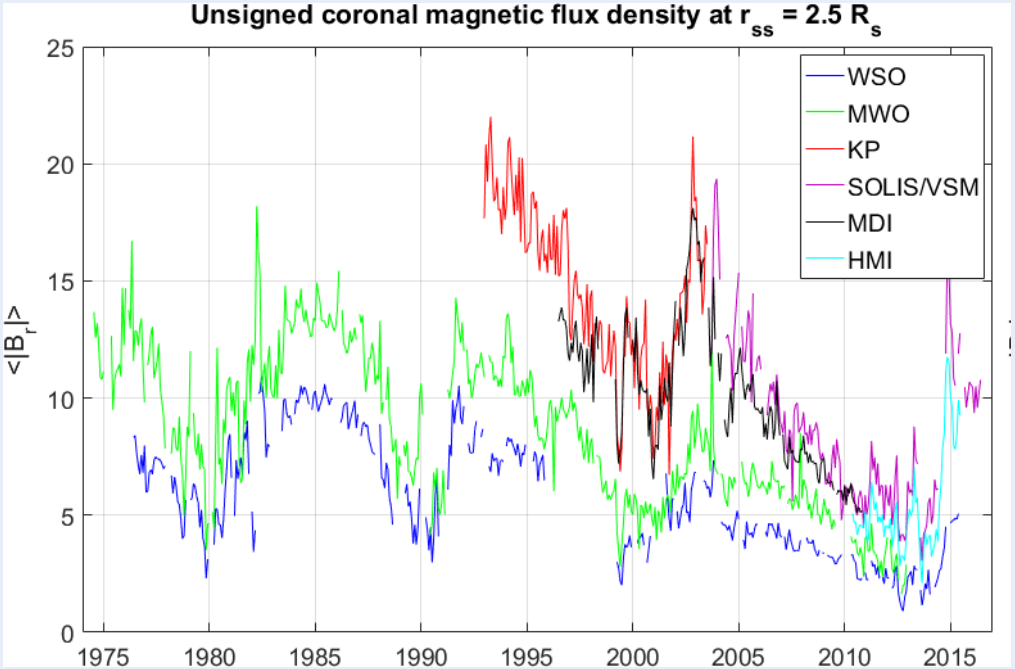


Fig. Typical coronal magnetic field structure in 1976, as calculated using the PFSS model.

Unsigned coronal flux densities from different observatories

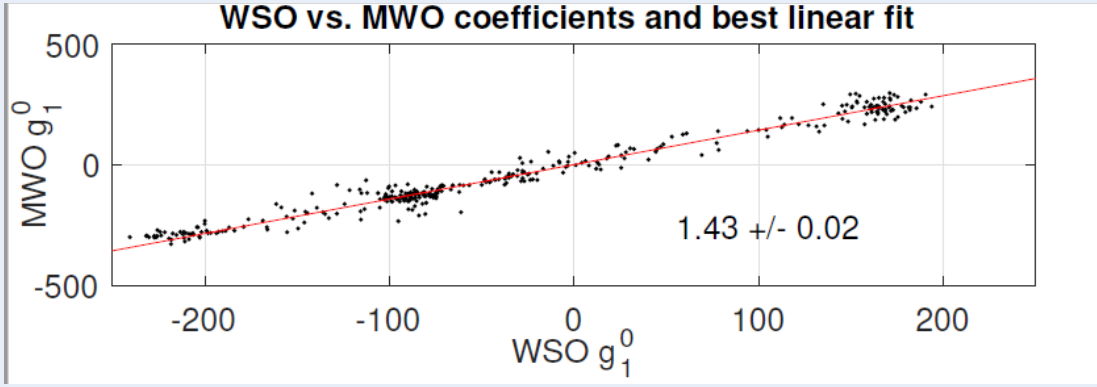
- The mean unsigned coronal magnetic magnetic flux densities (radial magnetic field intensities) derived from the photospheric magnetic field observed by several ground-based and space instruments differ considerably from each other.
- The absolute levels are very different, and mainly reflect the different spatial resolutions of the instruments.
  - Low resolution averages the small-scale magnetic field structures of opposite polarity
- The new, high-resolution instruments (SOLIS and HMI and even MDI) agree with each other quite well.
- However, the longest-running instruments (MWO, WSO) have much lower resolutions.
- => So, in order to have a consistent long-term series of coronal flux densities, **one must intercalibrate ("scale") the photospheric fields of the different instruments.**



New scaling method: harmonic scaling

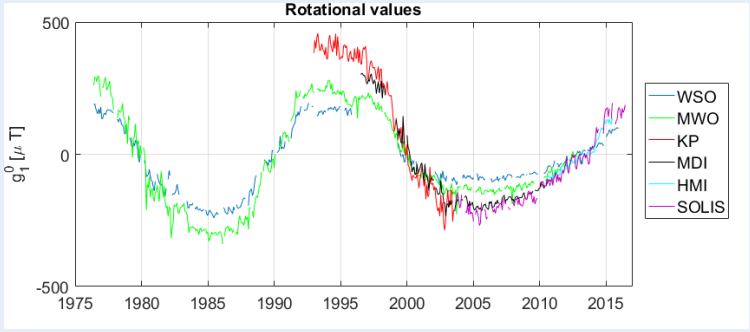
- Idea of harmonic scaling:
- Scale the spherical harmonic components between any two datasets, not the individual pixel values.

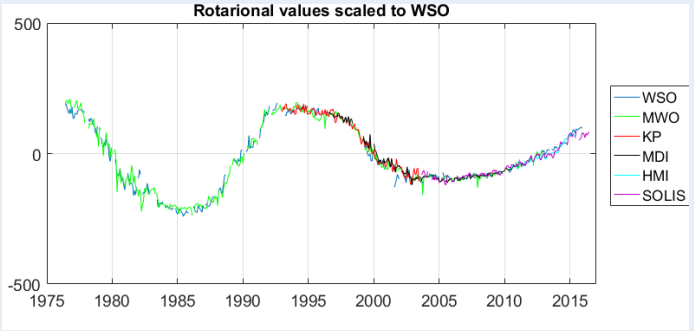
- For example, axial dipole component g_{10} for MWO is about 43% larger than for WSO. This ratio remains the same in time, even though the magnitudes vary over the solar cycle.



- Same method can be applied to all harmonics.

- All pairs of datasets with sufficient overlap can be scaled to each other.
- Below: all unscaled datasets of g_{10} (above) are scaled to WSO level (below).





Virtanen and Mursula, Astron. Astrophys., 604, 2017

Scaled coronal flux densities

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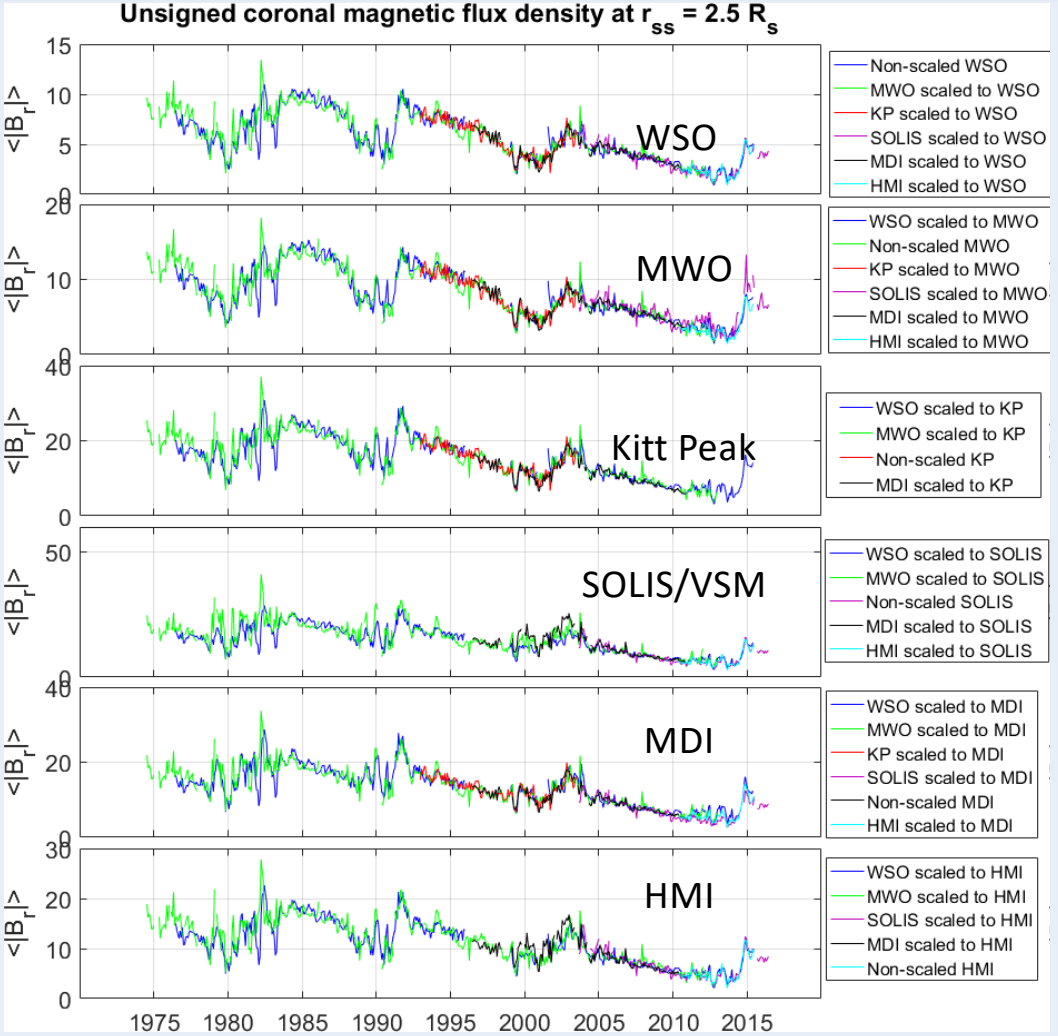
- We scale the harmonic coefficients of the photospheric field of the different datasets before calculating the respective coronal flux densities.
- We scale each dataset with respect to all other datasets that have sufficient overlap.
- There is a good agreement in unsigned coronal magnetic flux densities from different instruments.
  - There is a large decreasing trend from 1980s to 2010s.
  - Solar cycle maxima are in the declining phase.
  - There is often a local minimum at solar maxima.

Virtanen and Mursula, Astron. Astrophys., 604, 2017

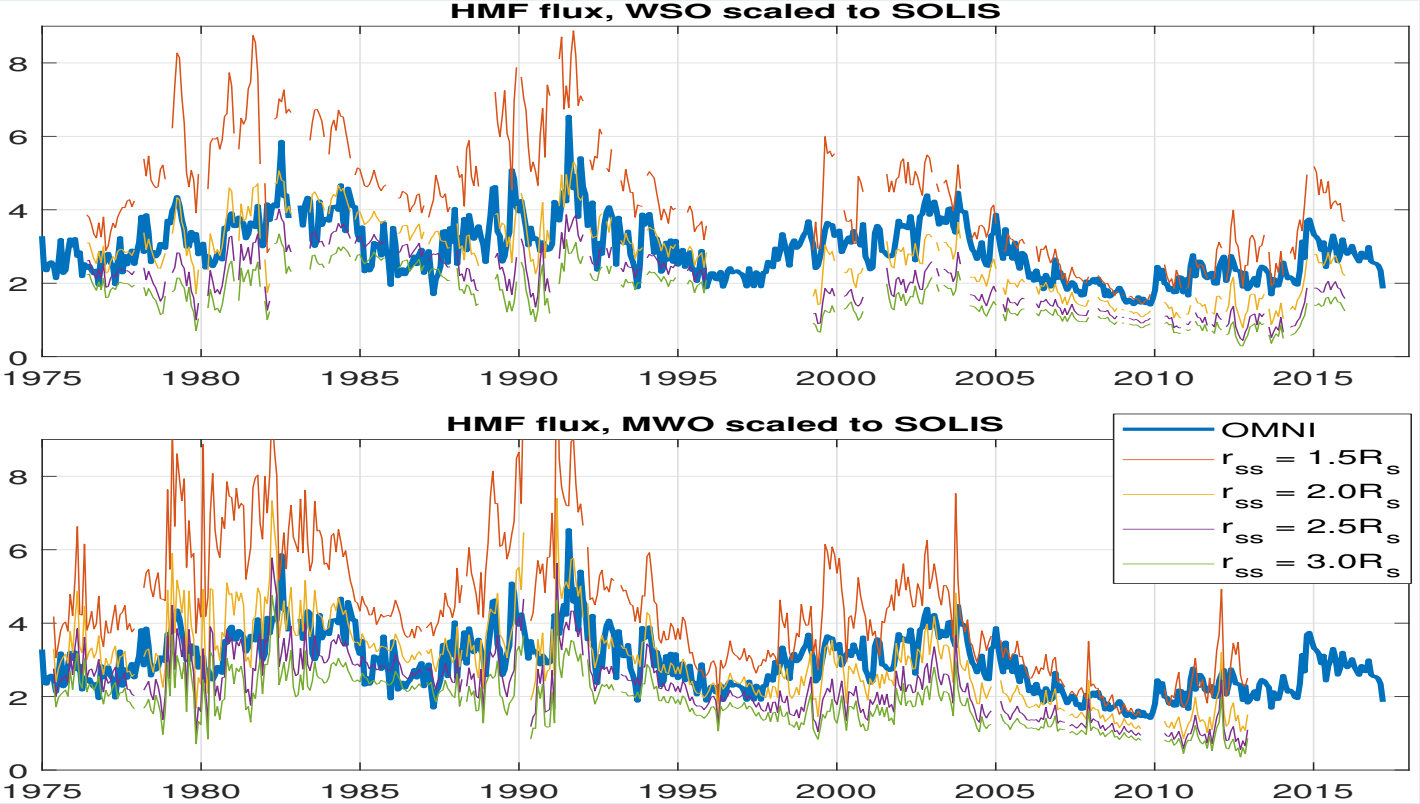


Coronal flux densities at 1AU vs. measured HMF

The HMF measured at the Earth's orbit (1 AU) shows a clearly weaker long-term decline in 1975-2017 than the coronal flux (for any fixed r_{ss} value).

For a small r_{ss} the coronal flux density can match the recent, small HMF flux but exceeds that in 1980s and 1990s.

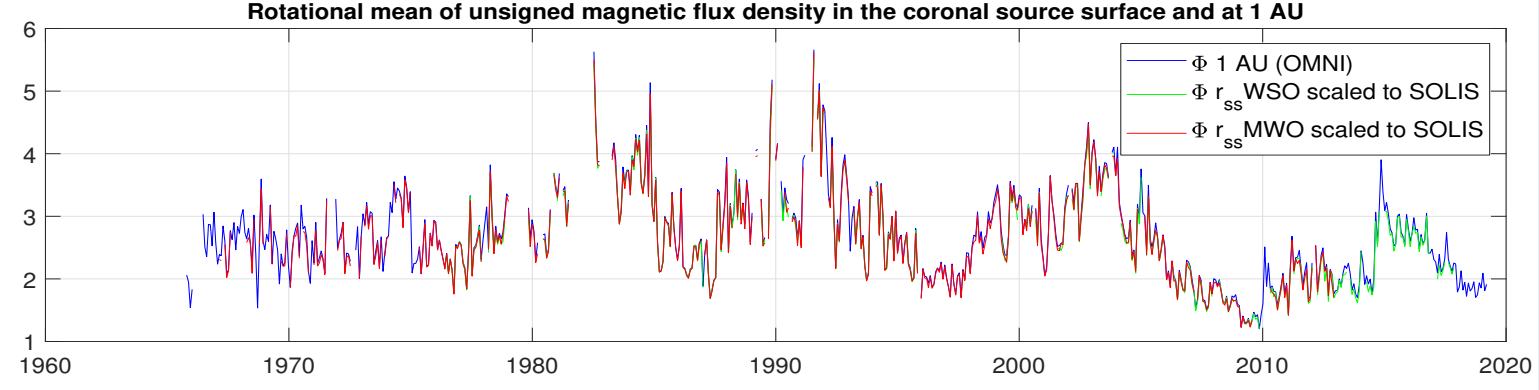
For a large r_{ss} the coronal flux density can match the early period, but is too low during the last decades.



Virtanen, Koskela and Mursula, ApJL, 889:L28, 2020

Coronal field at 1AU using optimum r_{ss} for each rotation

Varying r_{ss}, we can find an optimum value of r_{ss} for each rotation separately, for which the coronal flux density at 1AU will be exactly the same as the HMF measured at 1 AU.



Virtanen, Koskela and Mursula, ApJL, 889:L28, 2020

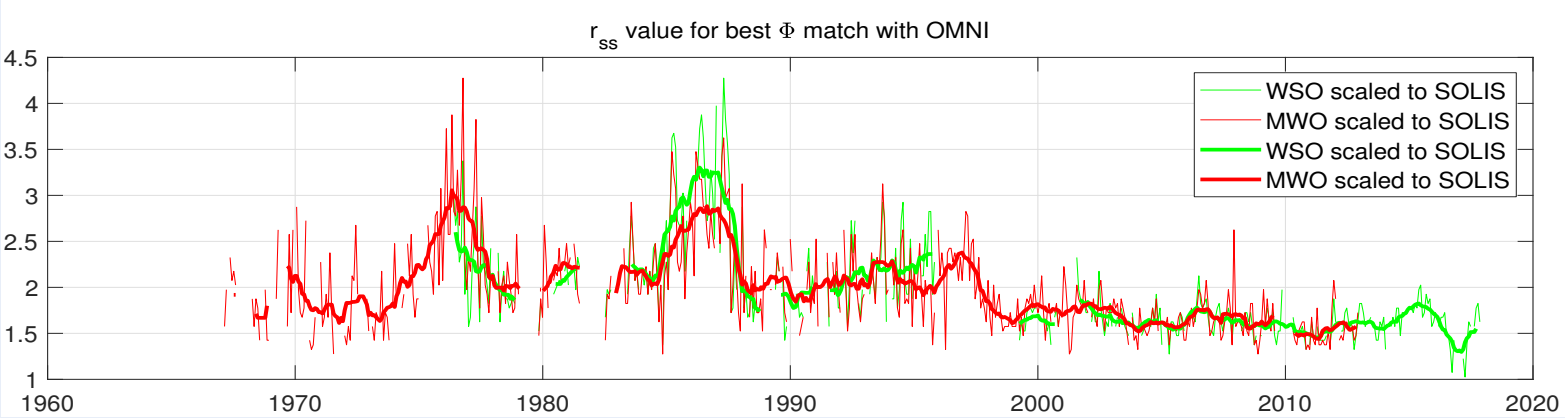
Optimum r_{ss}

There is an overall declining trend in optimum r_{ss}.

Most clearly there is stepwise decline in optimum r_{ss} in the late 1990s, from values above 2 to about 1.5. This implies a reduction to less than half volume.

Even thereafter, a weak declining trend in optimum-rss in 2000s (and 2010s?)

MWO and WSO closely agree on these changes.



Virtanen, Koskela and Mursula, ApJL, 889:L28, 2020

Coronal field structure in four minima

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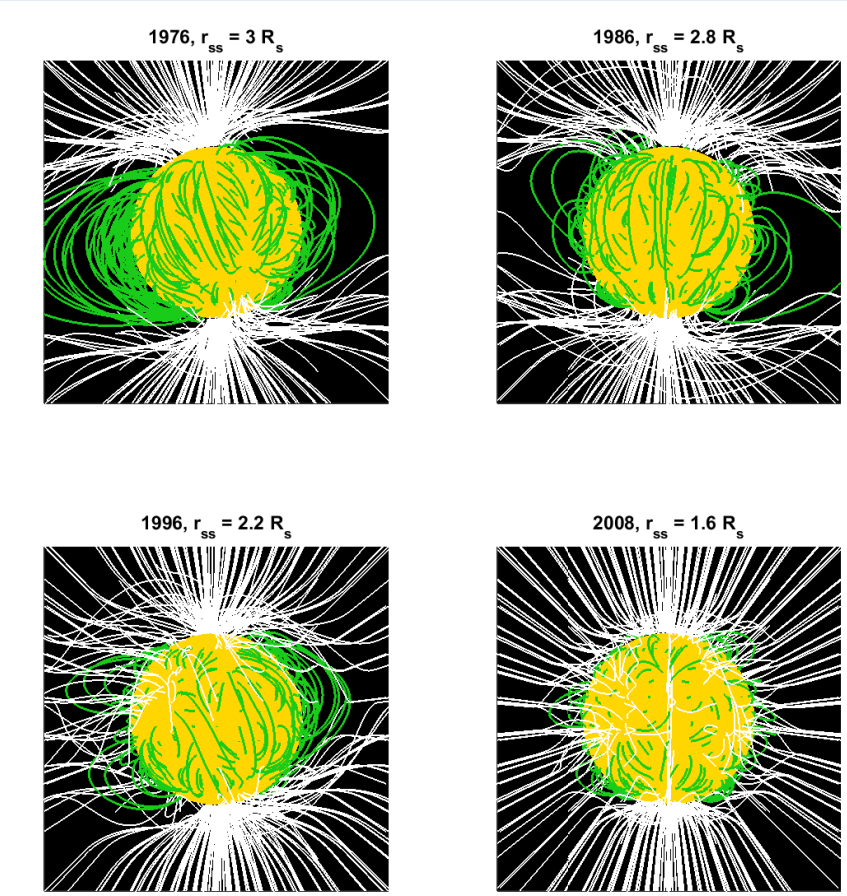
There was a systematic change in the minimum-time coronal magnetic field structure from 1970s 2000s.

In 1976, coronal closed fields were dominated by long inter-hemispheric field lines, reflecting strong polar fields and a large r_{ss} distance.

In 2008, corona had mostly intra-hemispheric field lines, reflecting weaker polar fields and a small r_{ss} distance.

Virtanen, Koskela and Mursula, ApJL, 889:L28, 2020



Coronal shrinking

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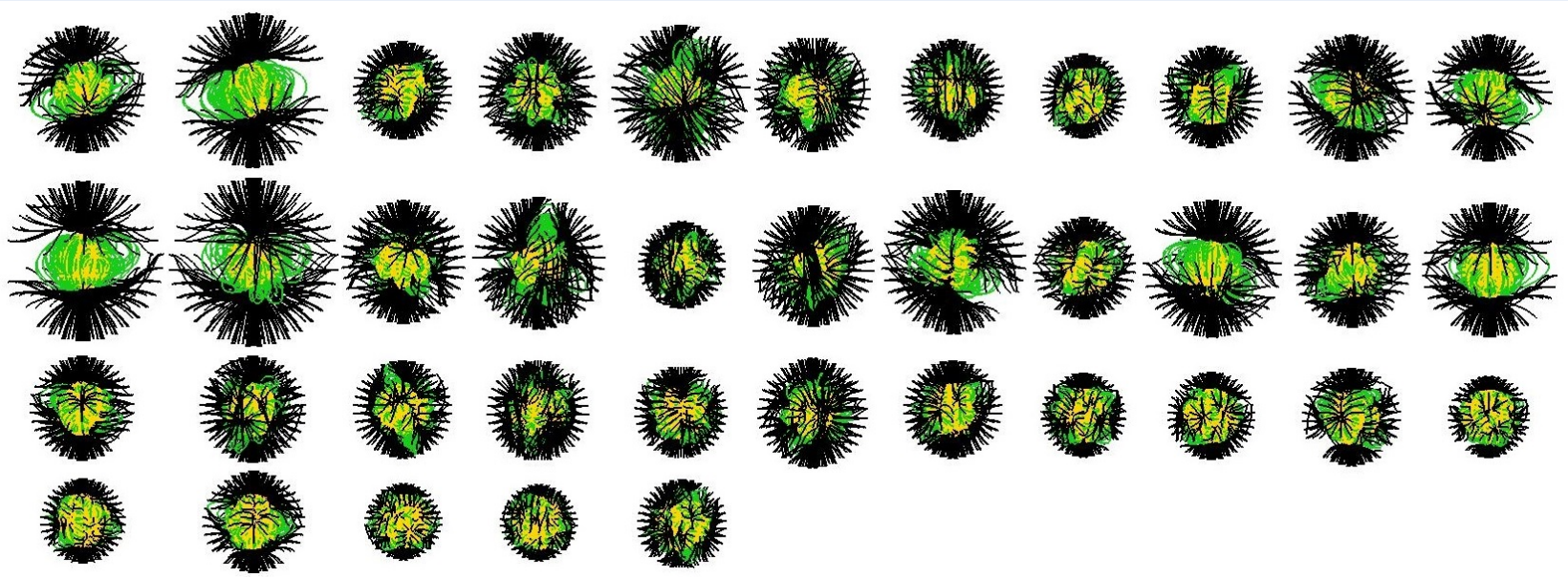
There is a systematic long-term change in coronal size!
Corona is shrinking since 1997. Current coronal volume is less than half of earlier.

Below: Coronal size and field structure for one rotation per year (summer solstice) in 1975-2012 (rows start at 1986, 1997, 2008)



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Thank you for your interest !

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