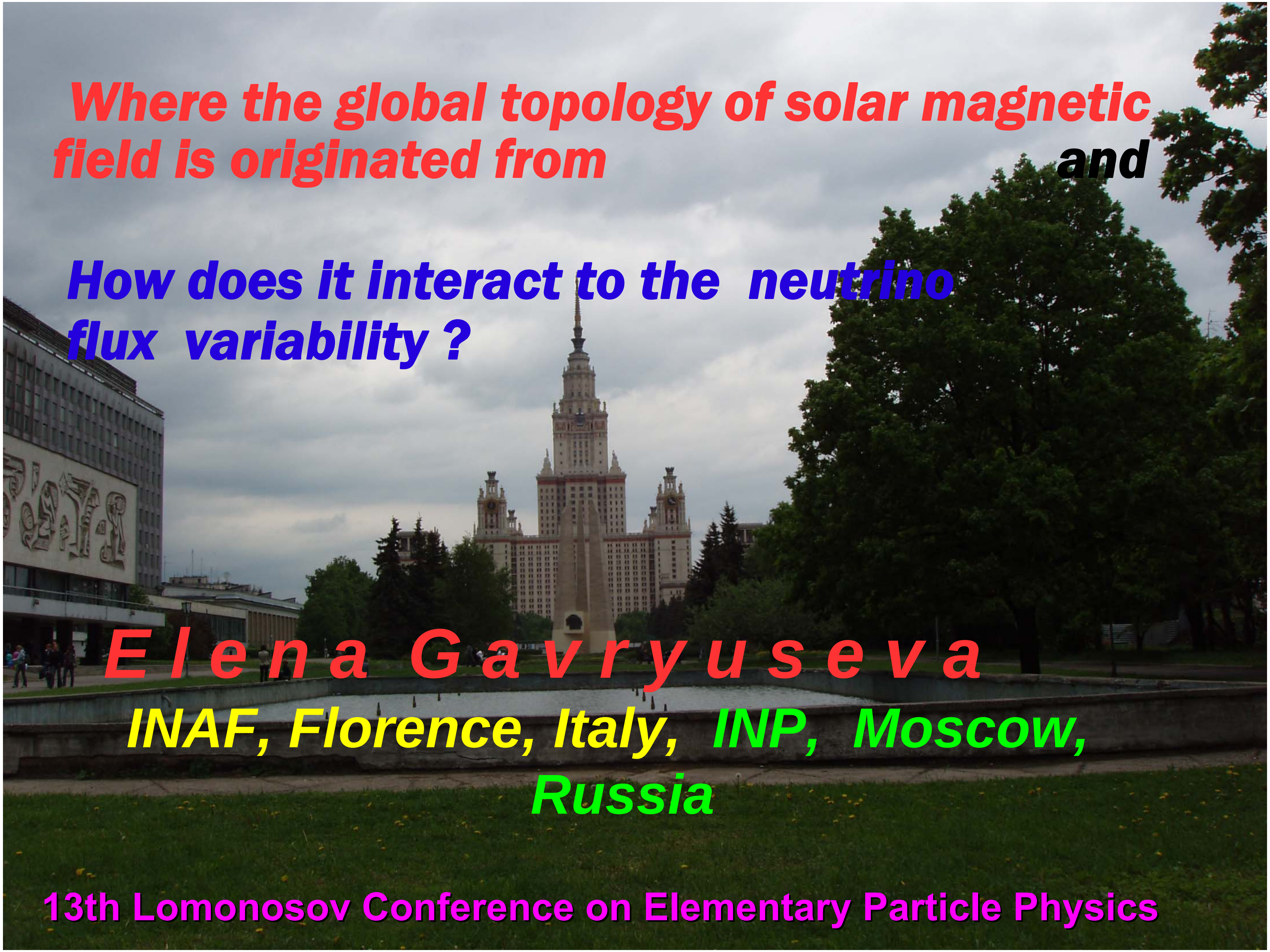

Where the global topology of solar magnetic field is originated from and
How does it interact to the neutrino flux variability ?
Elena Gavryuseva
INAF, Florence, Italy, INP, Moscow, Russia
13th Lomonosov Conference on Elementary Particle Physics

Subjects of discussion

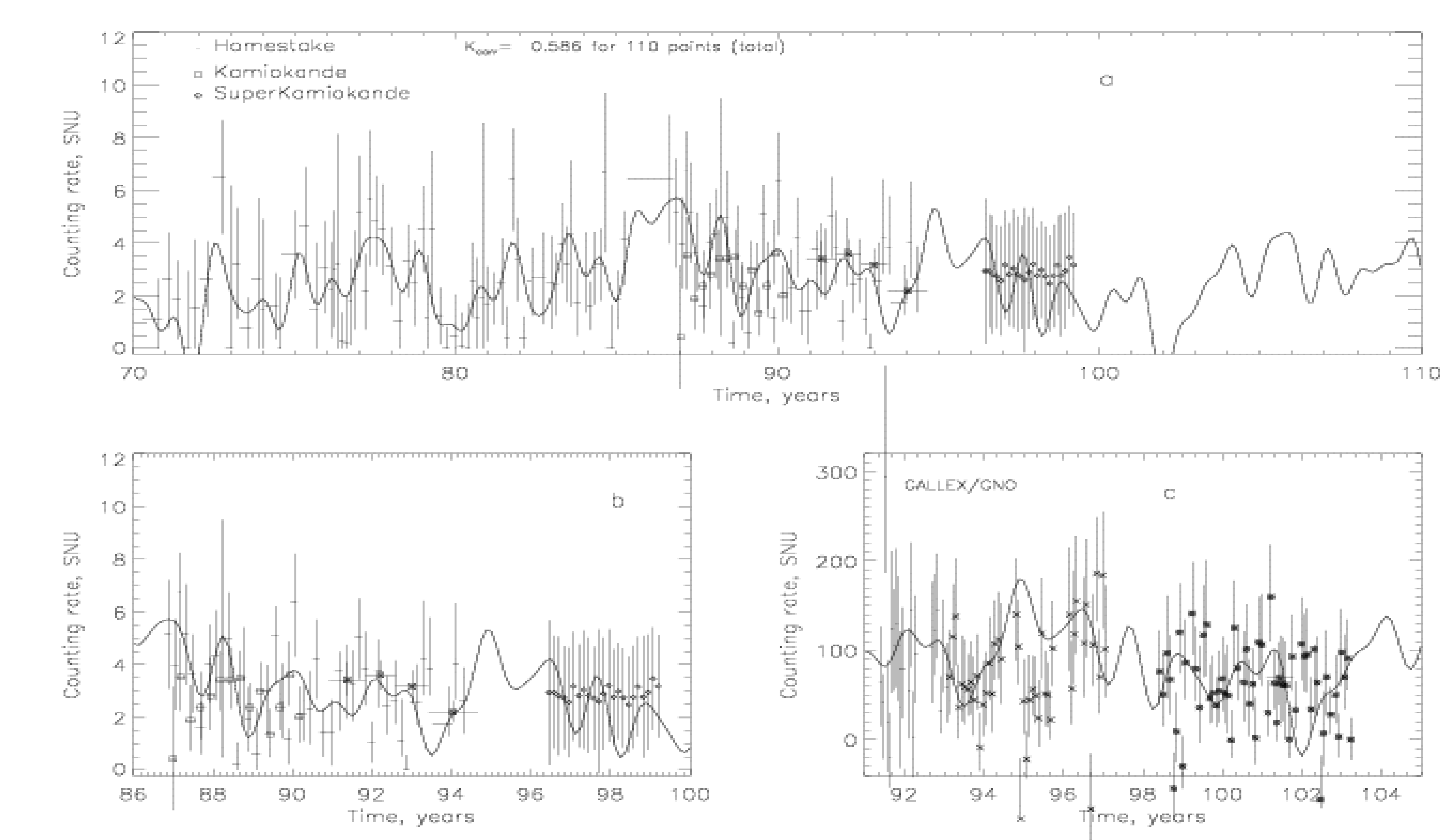
Latitudinal structure & rotation of the solar magnetic field and their variability

- **4-zonal structure with 20-22y period**
- **Running waves structure with 2-3y period**

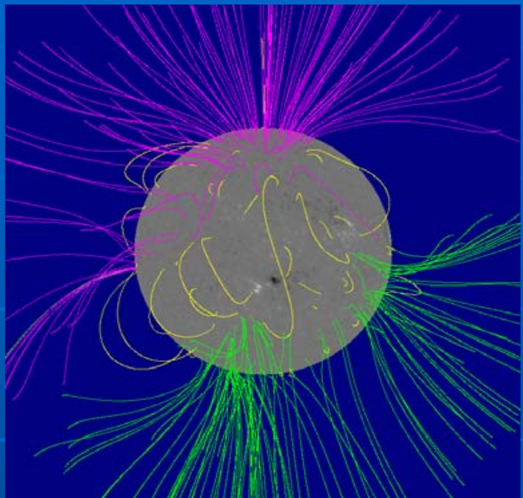
- **ν Variability of neutrino counting rate**

- **Model of Neutrino counting rate variability V_ν**
- **Model and solar diameter**
- **Model and magnetic field intensity**
- **Predictions of the model**

Neutrino counting rate in Homestake, GALLEX/GNO, Kamiokande detectors & model



Magnetic Field: Structure & Origin



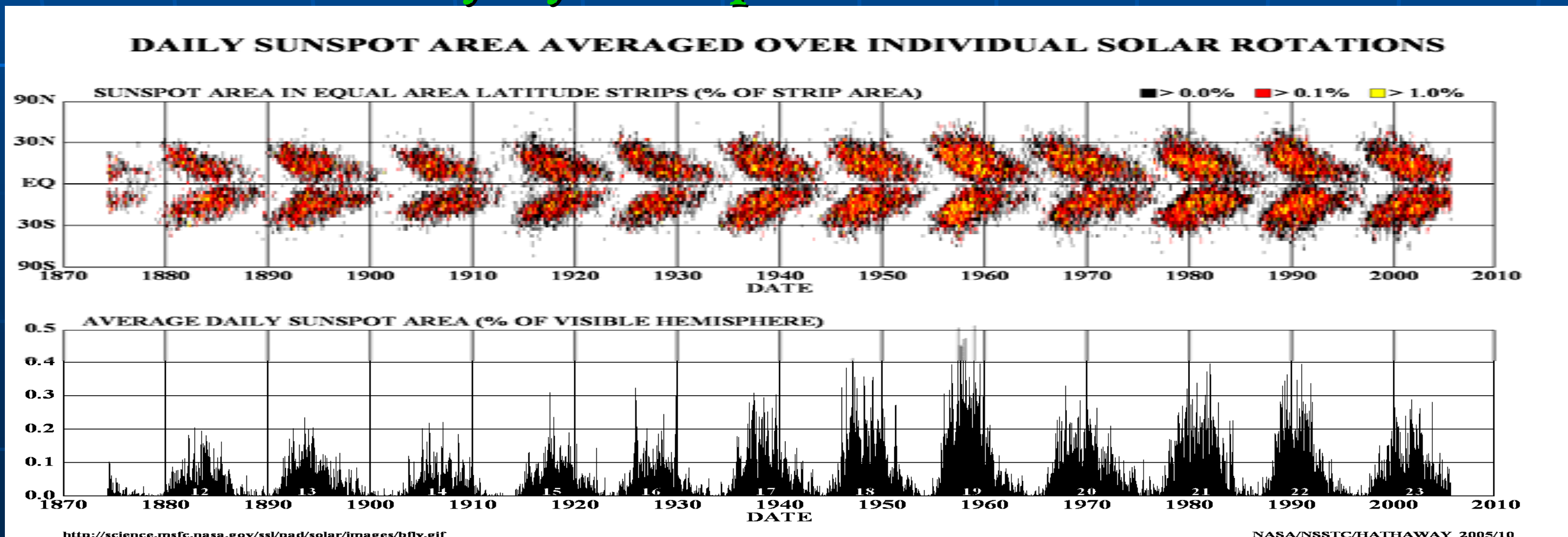
- **Solar Magnetic Field (SMF) can be measured in the Photosphere only.**

General questions:

- **Where the SMF is originated?**
- **What is the SMF structure?**
- **What are the SMF dynamics?**

Solar Activity Properties:

1. Latitudinal drift of Sun Spots

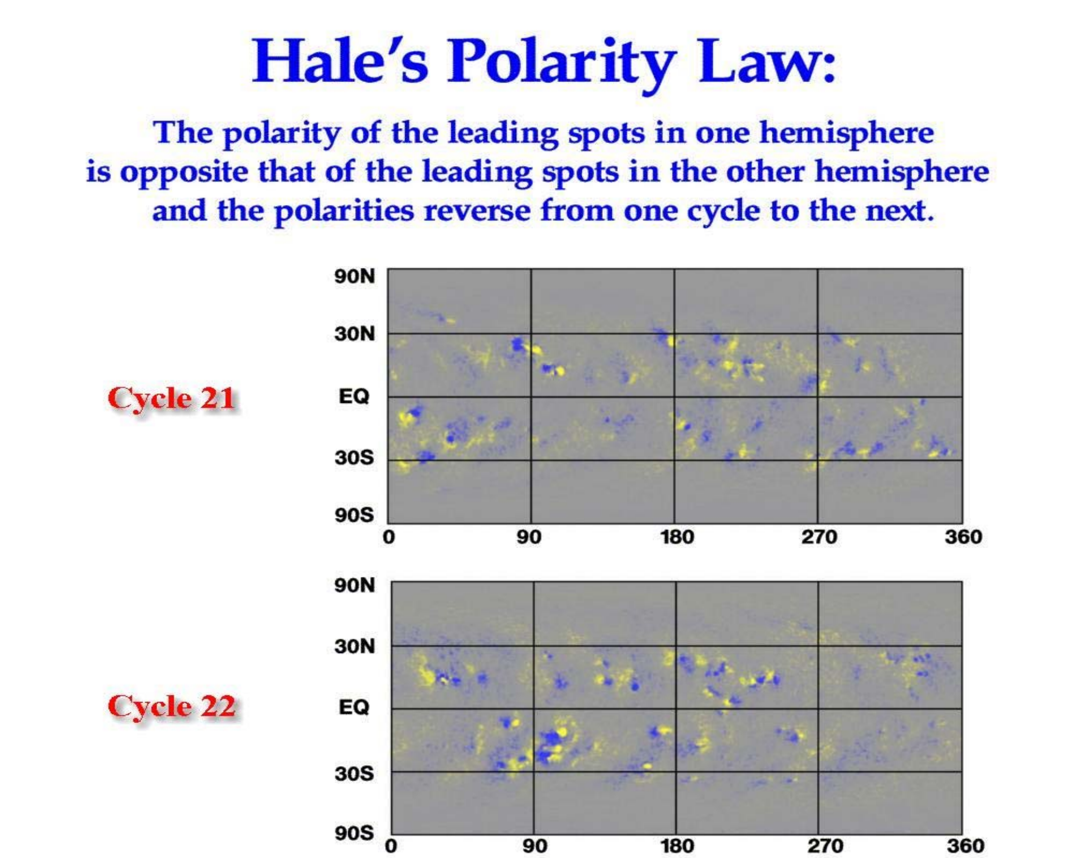


Butterfly Diagram

SSN Number

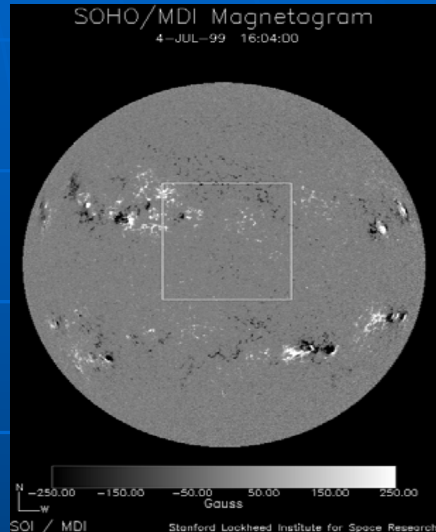
Solar activity properties:

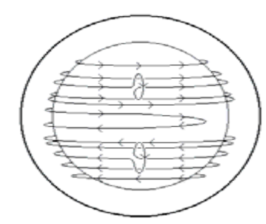
2. Dependence of Active Regions Polarity on the Cycle and on the Latitude



- **Solar Surface**
- **Light is +**
- **Dark is --**

- **Dynamo:**
- **α– and**
- **β–effects**

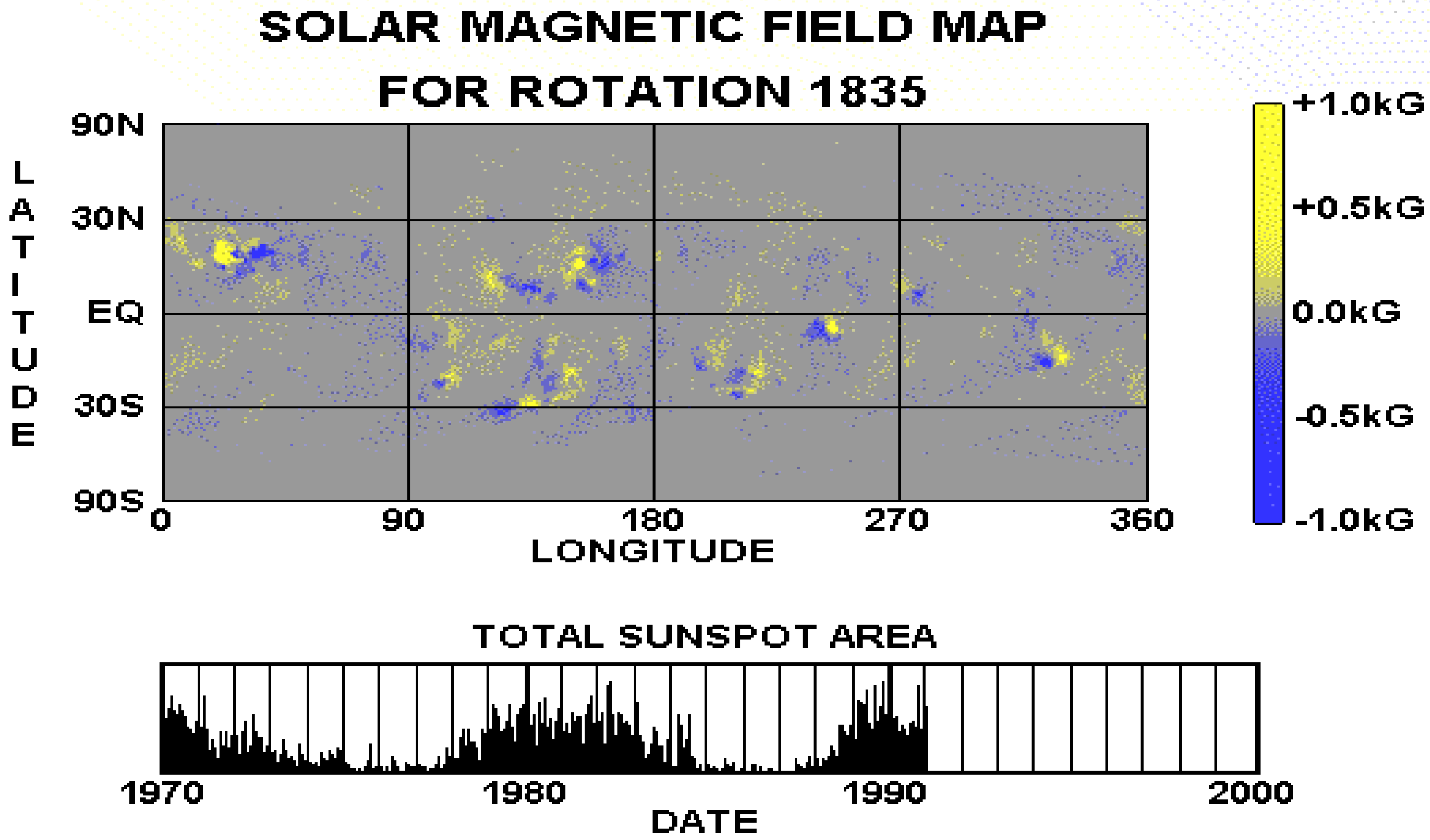




The α-effect

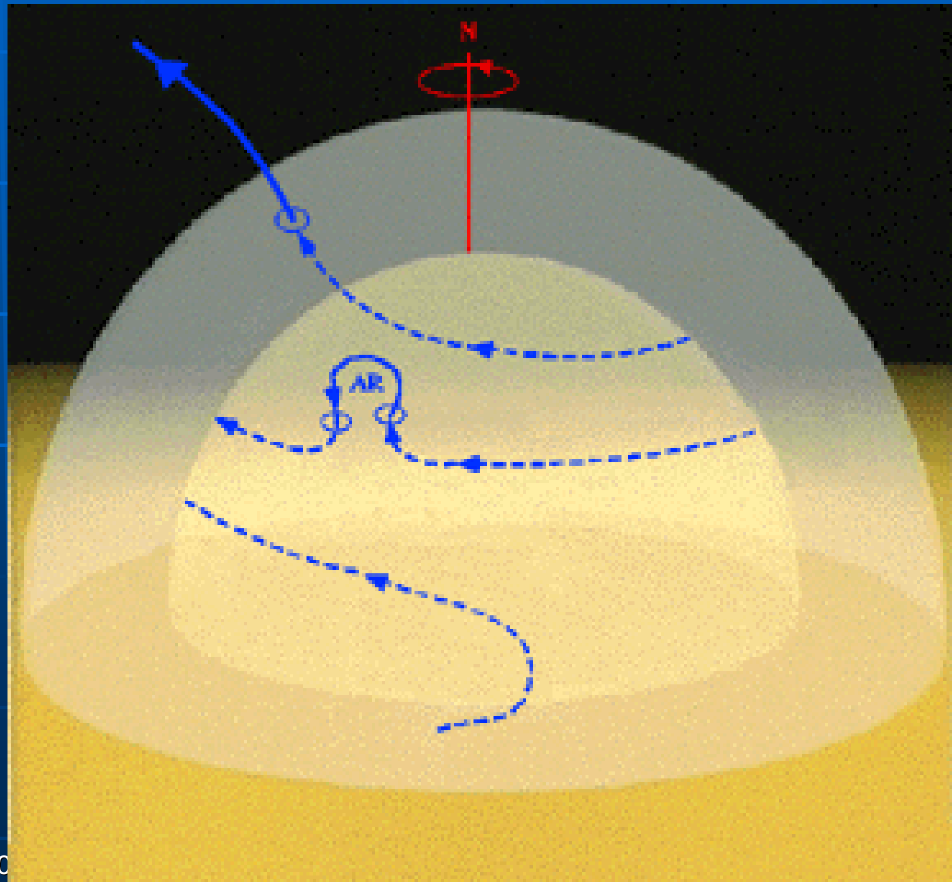
It is well known that there are two belts of the sunspots and two quiet polar casps of a certain polarity inverting each 11- years during maximum of solar activity.

Sunspots magnetic field & Area in time, courtesy of D.H.Hathaway

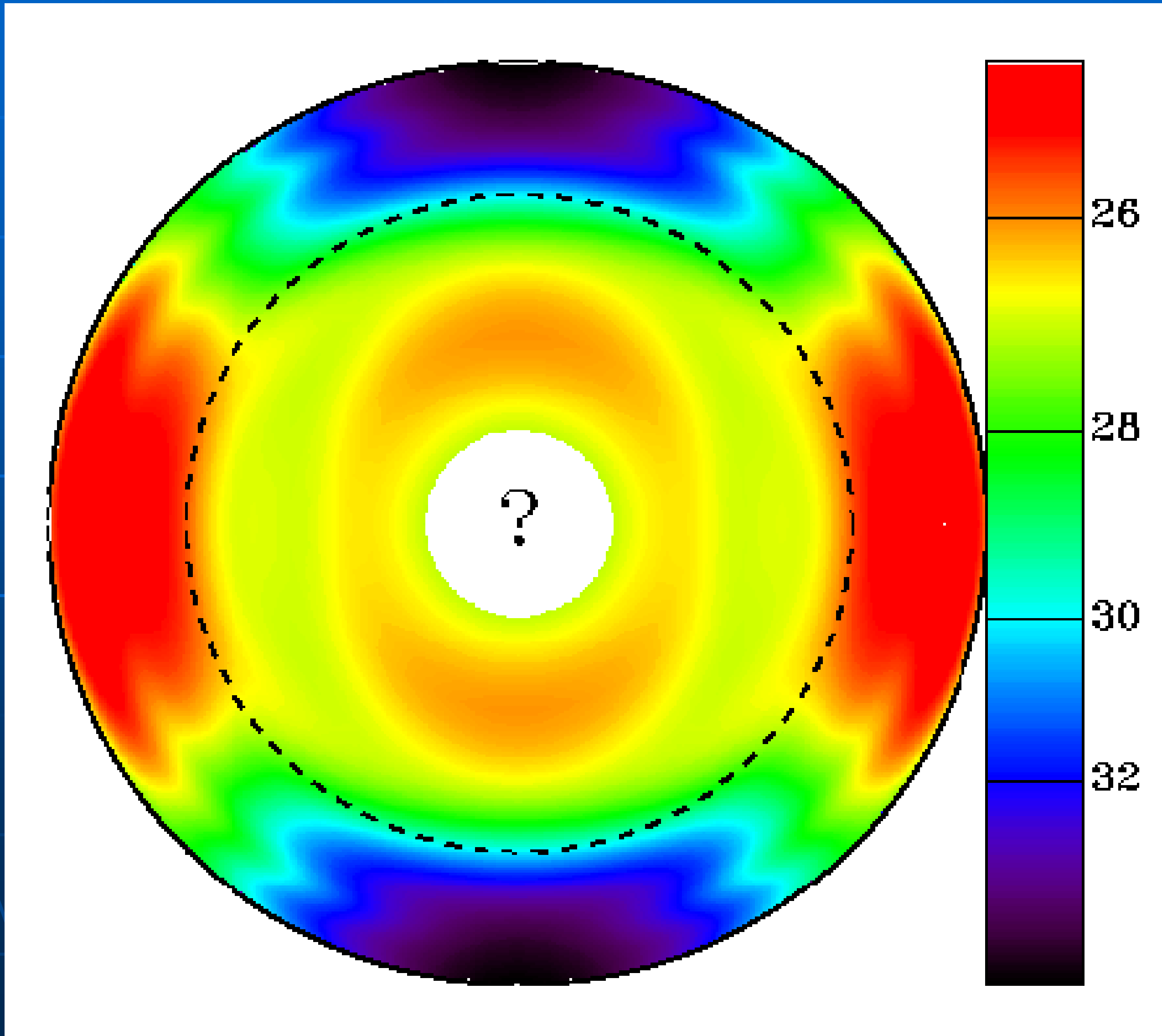


Solar Magnetic Fields

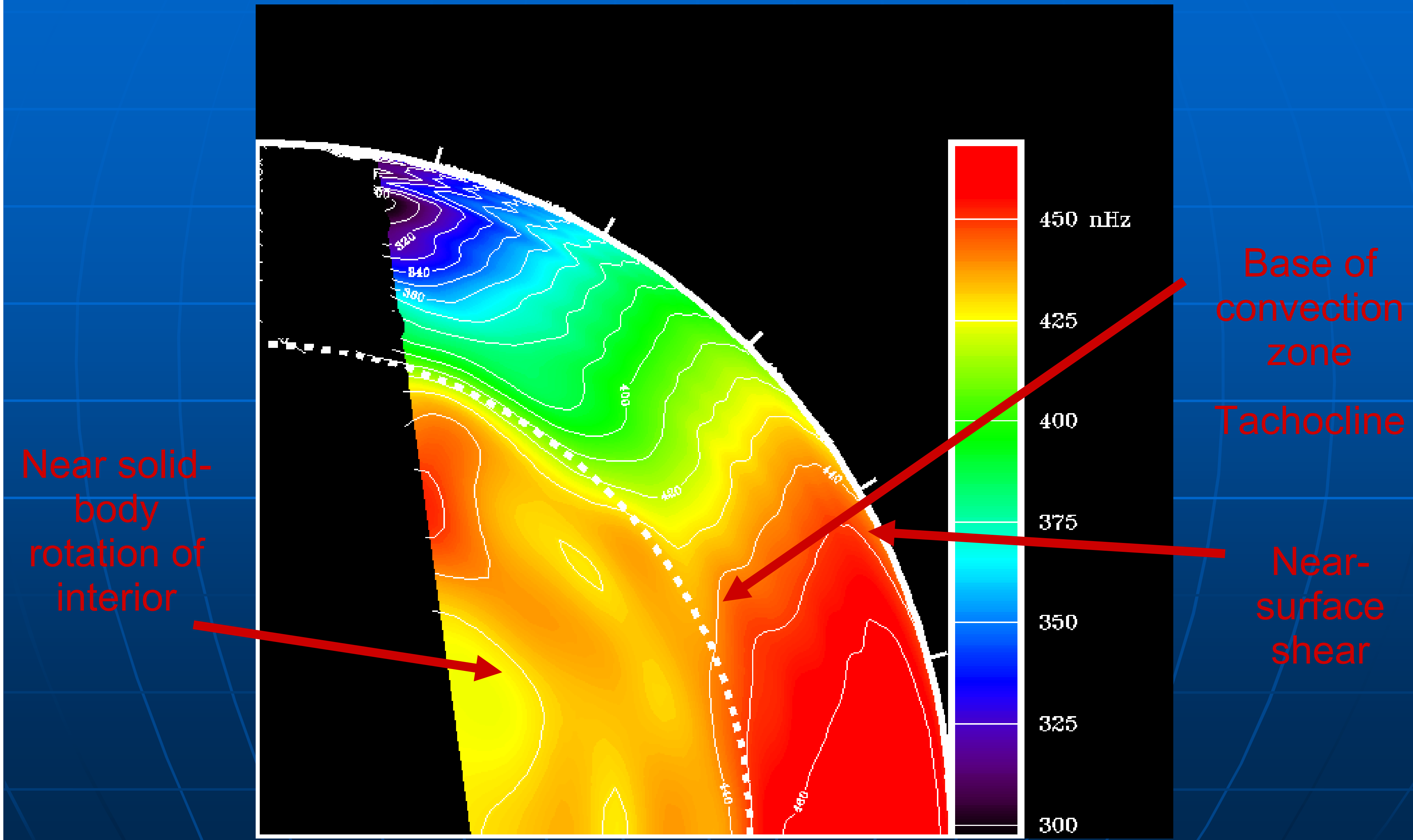
- Solar magnetic fields have long been believed to be generated by a solar dynamo, in which the turbulent inner motion generates the magnetic fields we see.



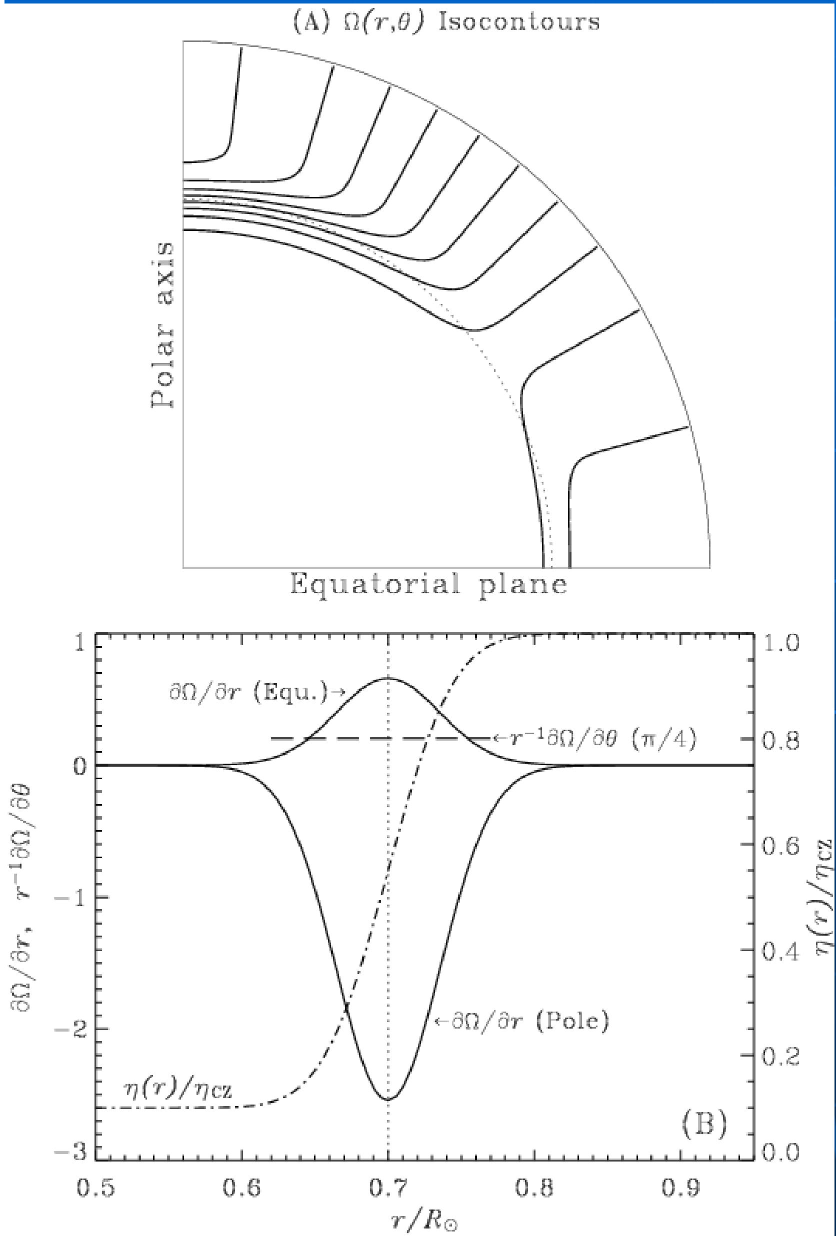
Rotation of solar interiors



Inferred solar internal rotation

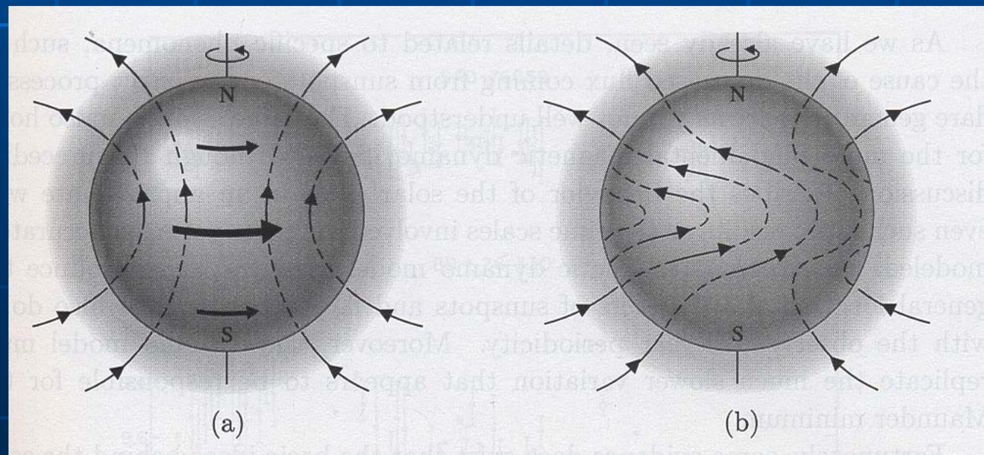


For the solar cycle, the driving velocity shear is believed to come from differential rotation

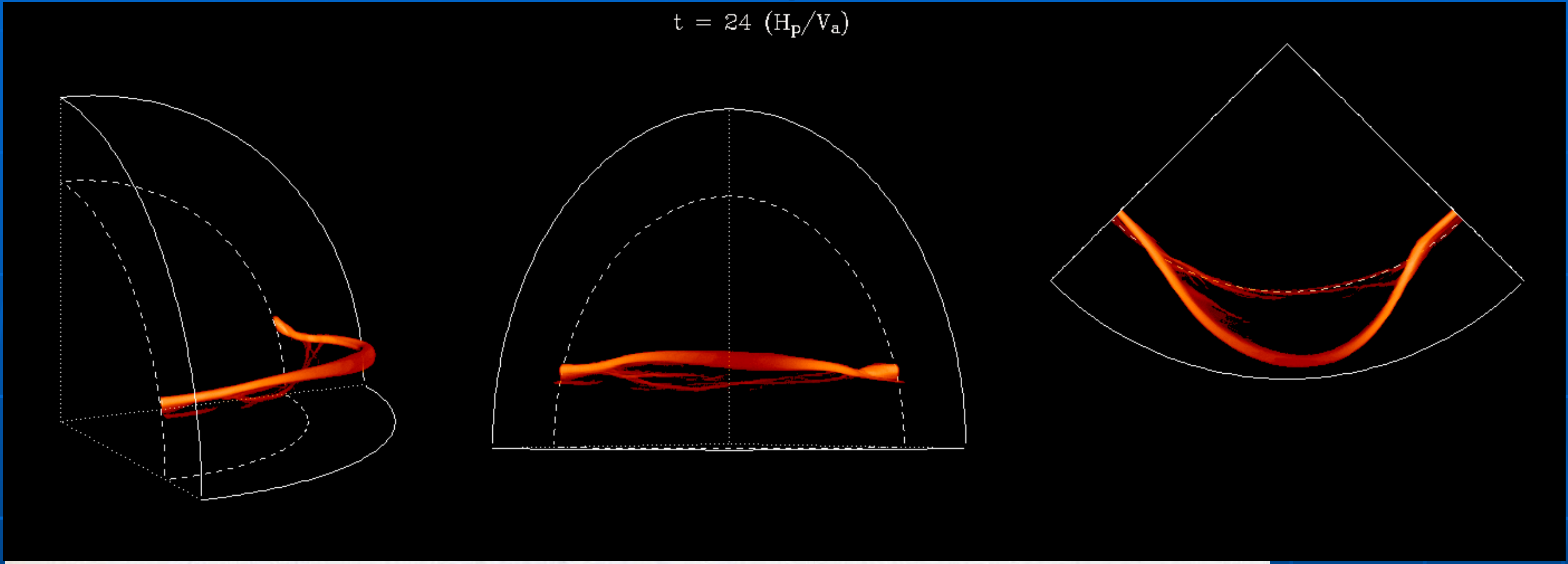


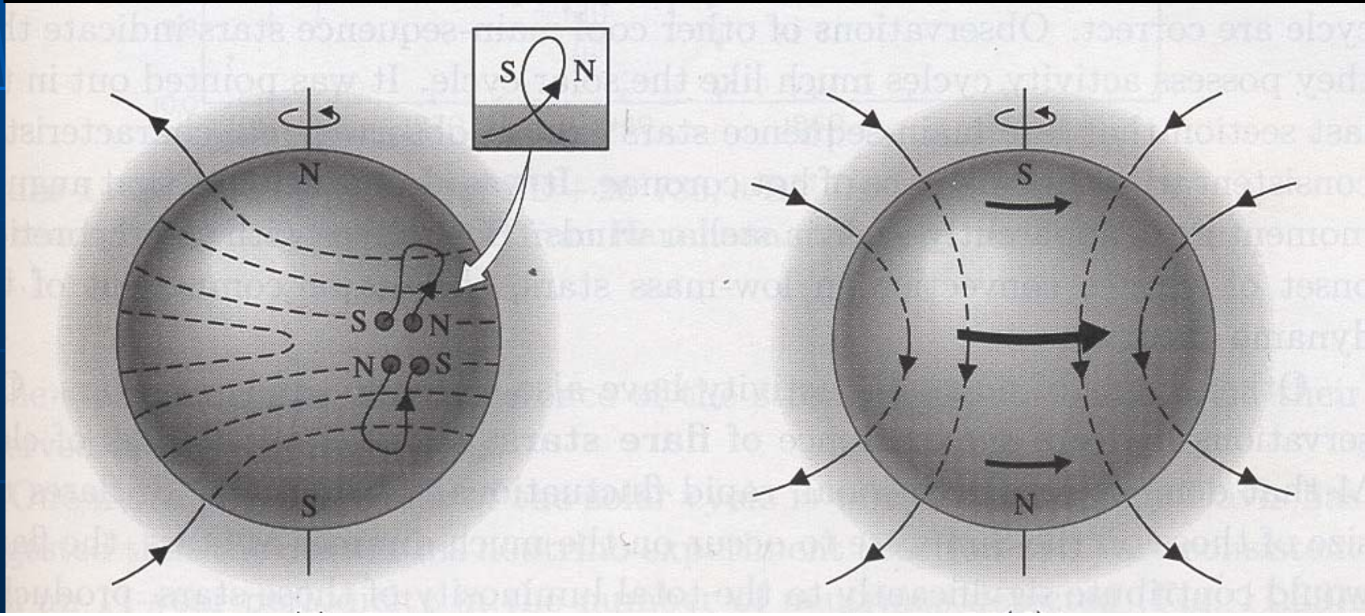
Differential rotation will act to stretch out an initially poloidal (N-S or radial) magnetic field into the azimuthal (toroidal) direction

Ω - effect.



The toroidal field erupts, is twisted by the Coriolis force, and generates a new poloidal field of the opposite sign, α- effect





WSO data

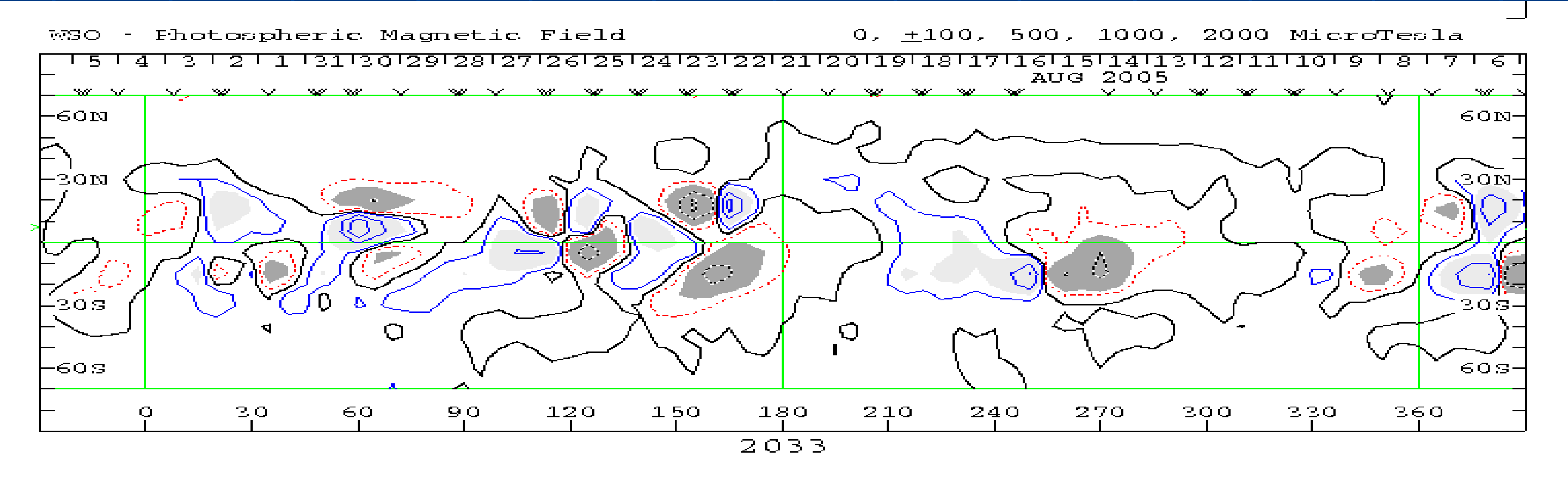
- The observations of the large scale magnetic field in the photosphere taken at the **Wilcox Solar Observatory (WSO)** since May 27, 1976 up to 2007 have been analyzed (http://wso.stanford.edu/synoptic.html).

- This interval of time covers the **solar activity cycles No 21, 22 and 23** and corresponds to the Carrington Rotations (CR) since 1642 to 2050.

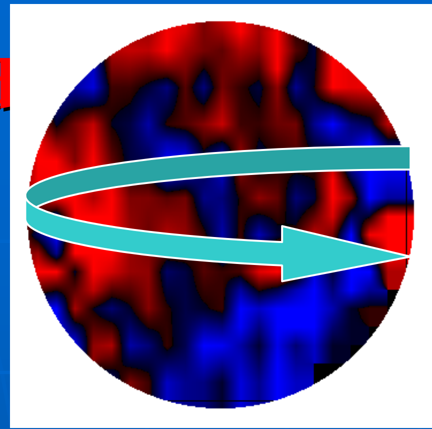
- The line-of-sight component of the photospheric magnetic field (SMF) is measured by the WSO's Babcock solar magnetograph using the **Zeeman splitting of the 525.02 nm Fe I spectral line.**

- The grid of the available data is made of **30 equal steps in latitude *sine* from 75.2 North to 75.2 South degrees and of** 5 degrees steps in heliographic longitude.

- Each longitudinal value is a weighted **average** of the observations made in the longitudinal zone **within 55 degrees around central meridian**.



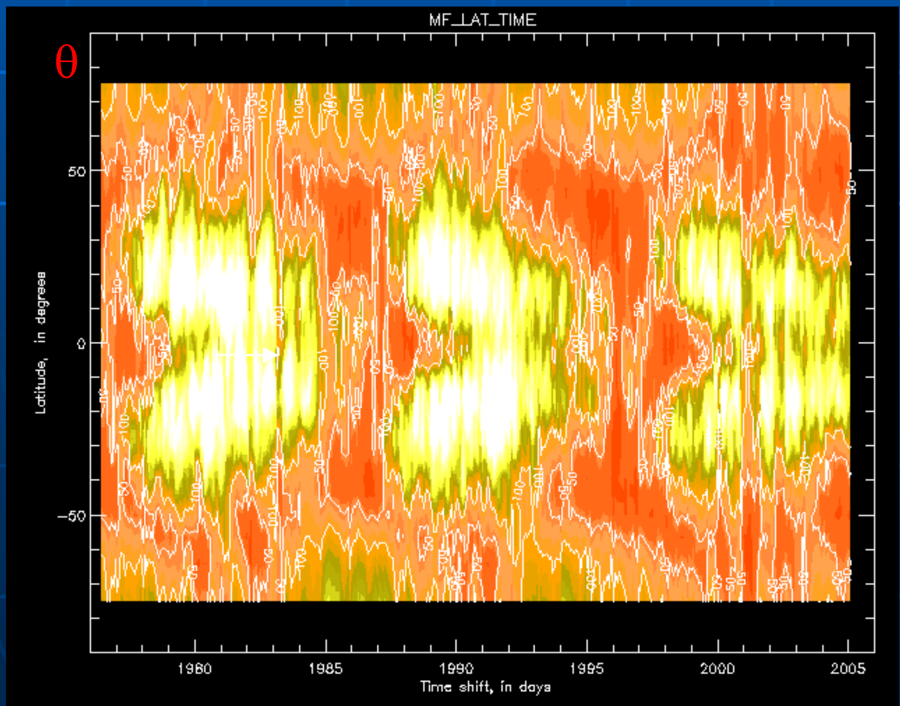
Latitudinal structure of Solar Magnetic Field



Mean Latitudinal Field over 1 or more solar rotations was calculated. Let us call this field as a ***latitudinal magnetic field***

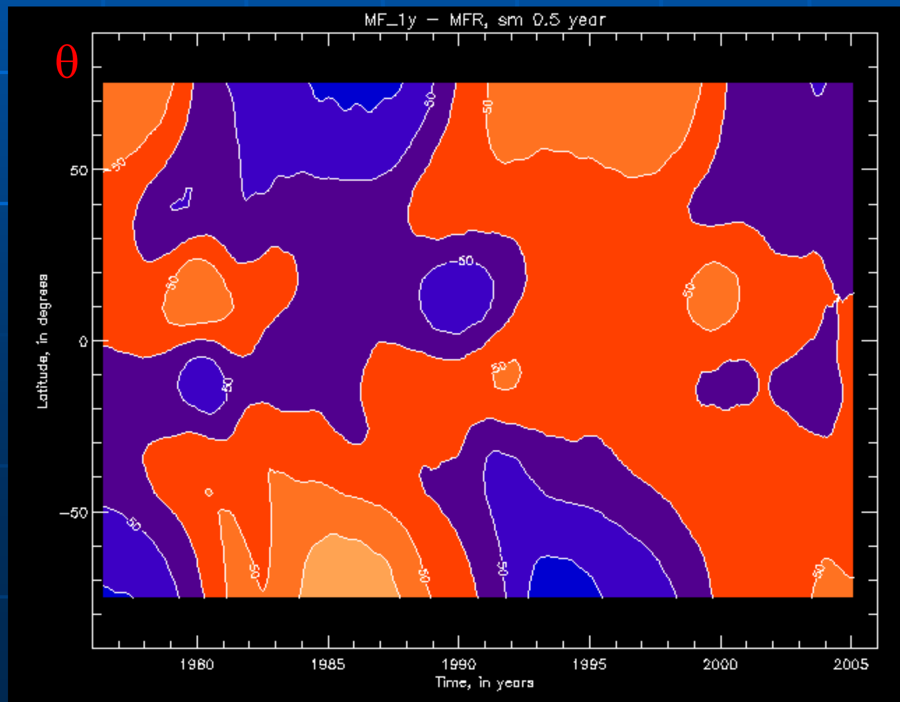
Magnetic Field Intensity

mean over 1 CR

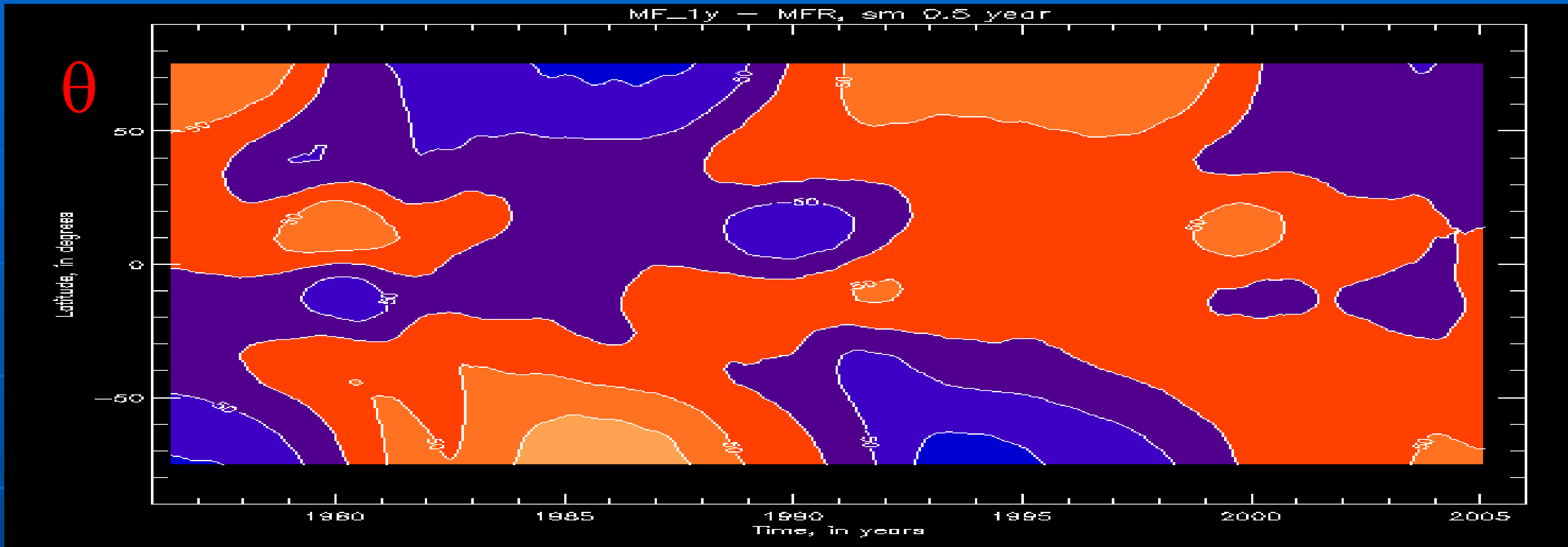


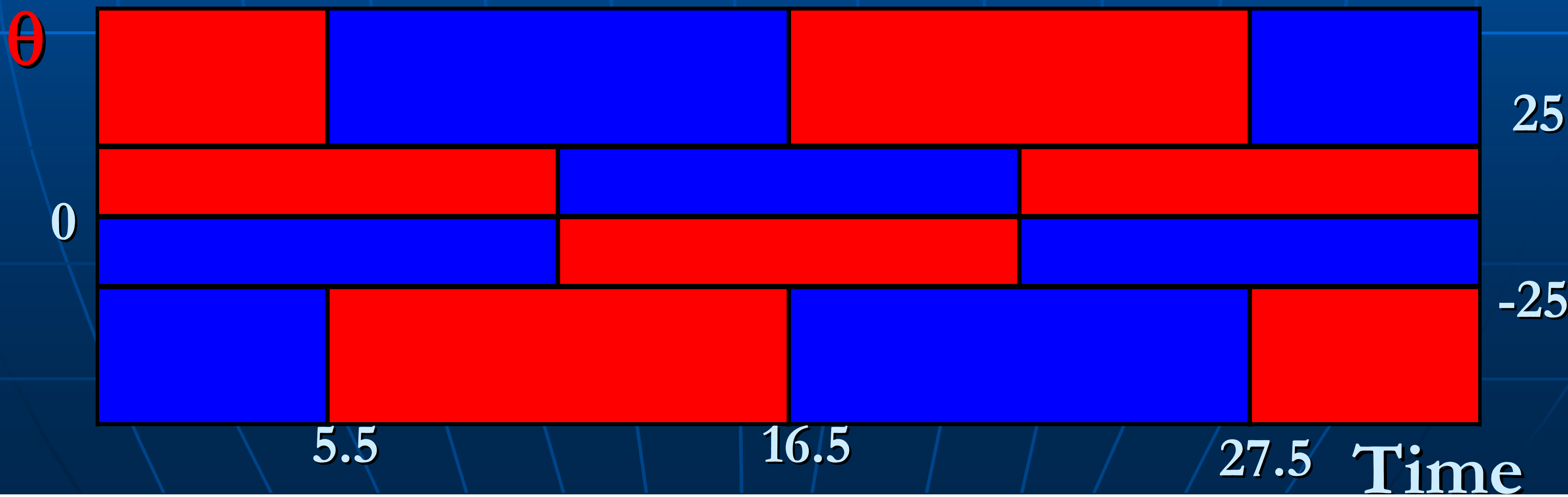
Magnetic Field

mean over 1 CR

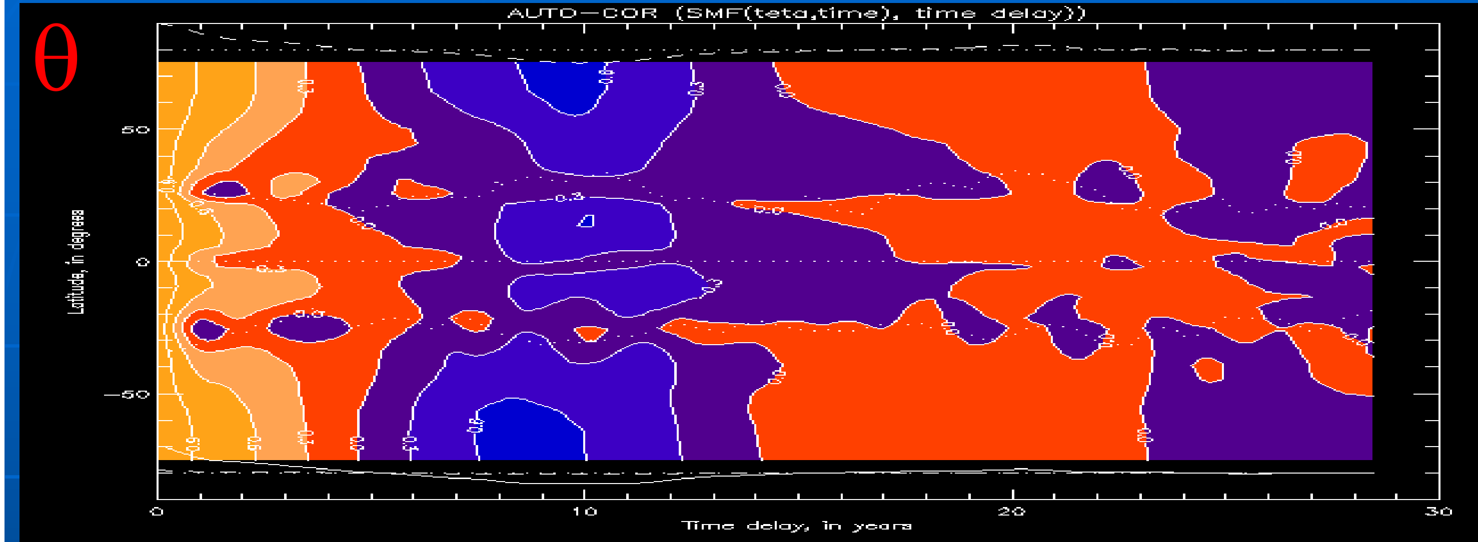


4-zonal latitudinal structure



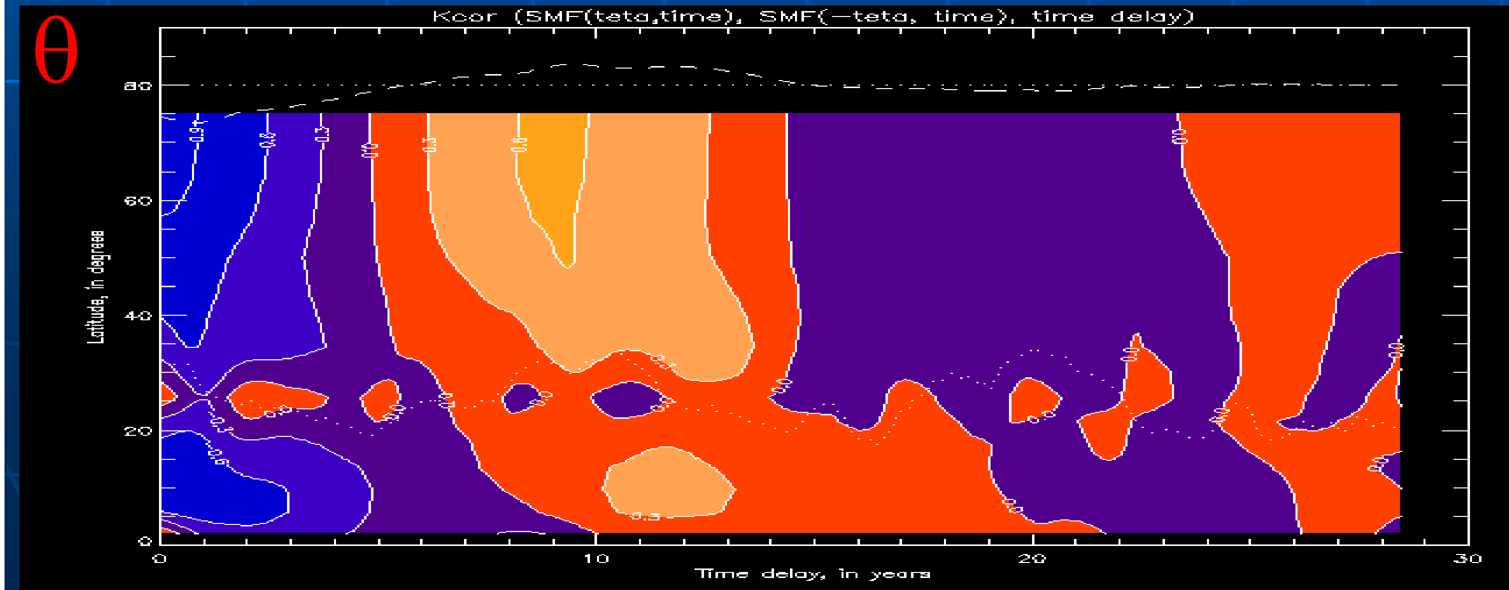


K auto-correlation SMF(θ)



18-22–year periodiciy
No correlation at + / -25degrees

K cor (SMF(θ), SMF(-θ))



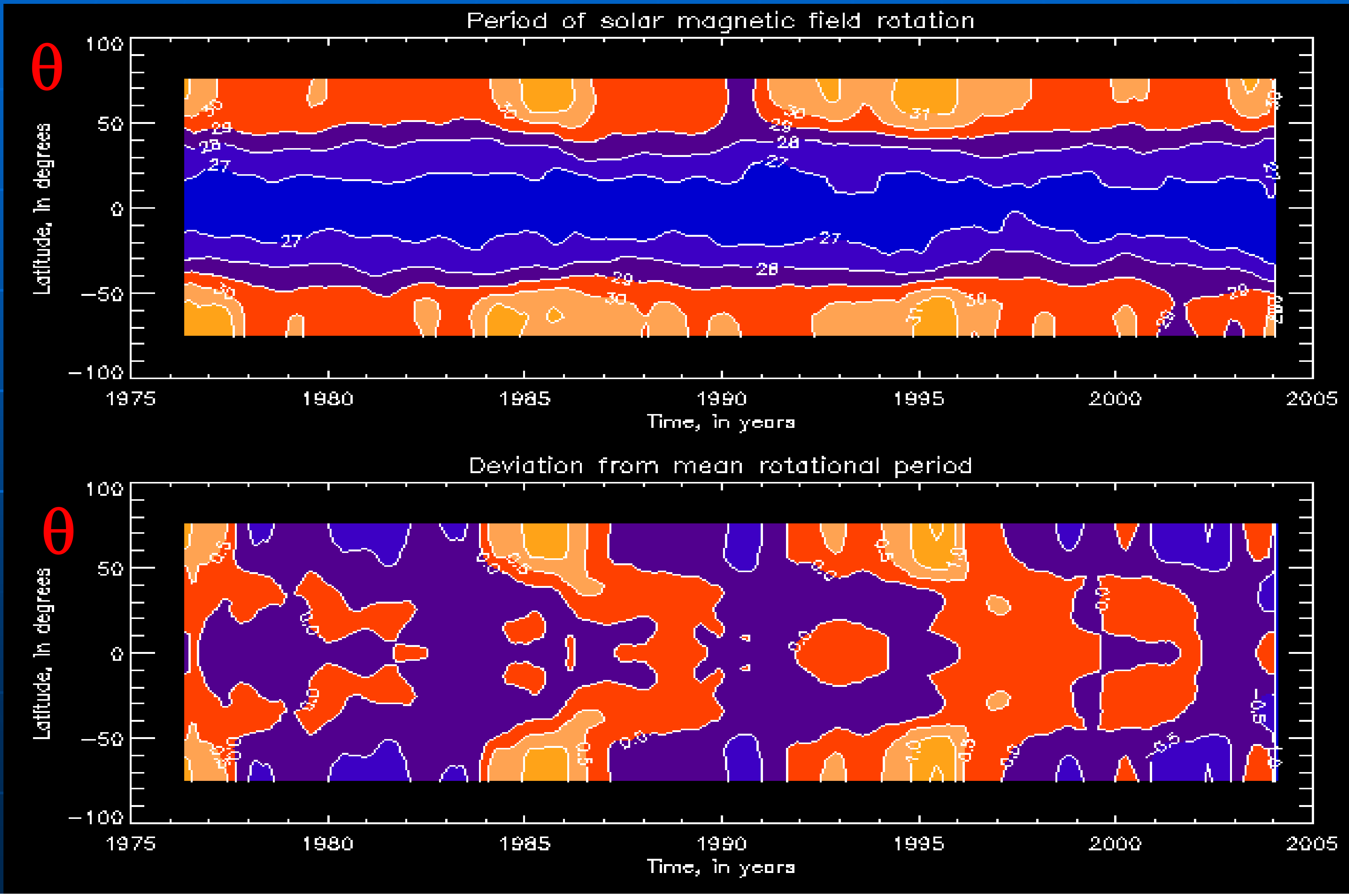
Anti-correlation at 0- shift

9-11 year periodicity

No correlation At + / -25 degrees

Differential Rotation of the SMF

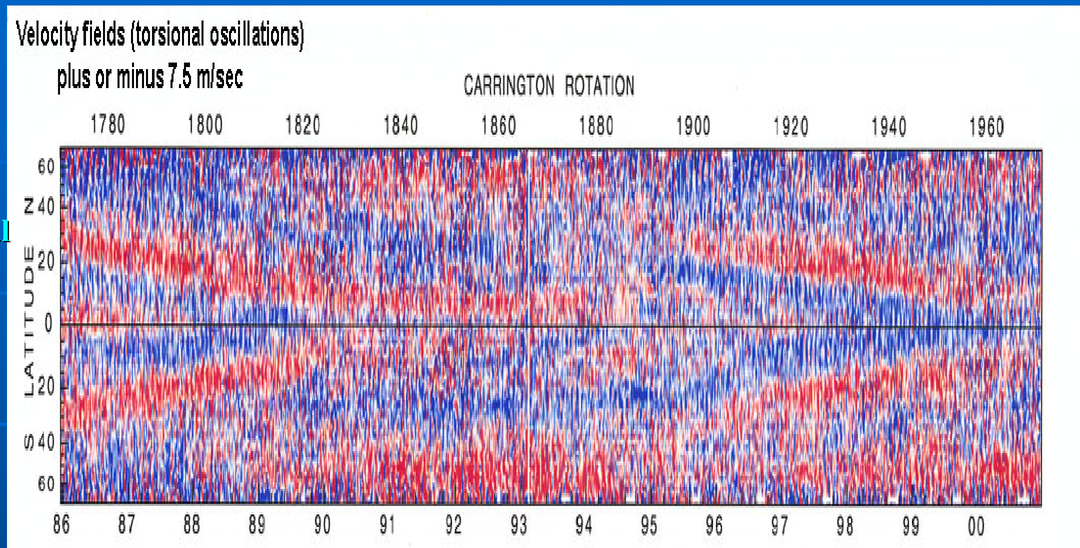
Sideral Periods & Deviations from P mean, in days



Torsional waves, $P(\theta, t) - P(\theta)$

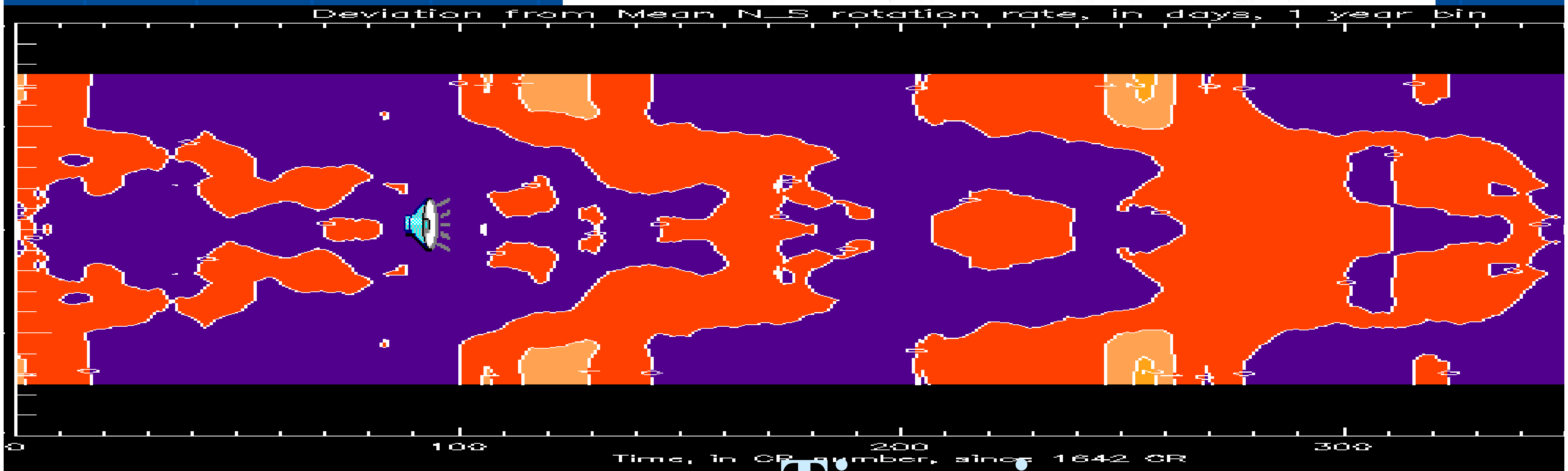
The torsional waves firstly discovered by Howard and LaBonte in sunspot rotation are present in the magnetic field rotation rate as well (Snodgrass, 1985, 1987; Gilman and Howard, 1984; Makarov et al., 1997) up to high latitudes as it is seen on the bottom plot of Fig. 5. The 11-year variability of the deviations of the period from the mean one in the sub-polar zones correspond to the torsional waves. The rotational rate of the pre-equatorial zones varies in time with a periodicity of 55--60 CR about (4 -- 5 years).

Doppler velocity, **Howard R, LaBonte B.J., 1980**



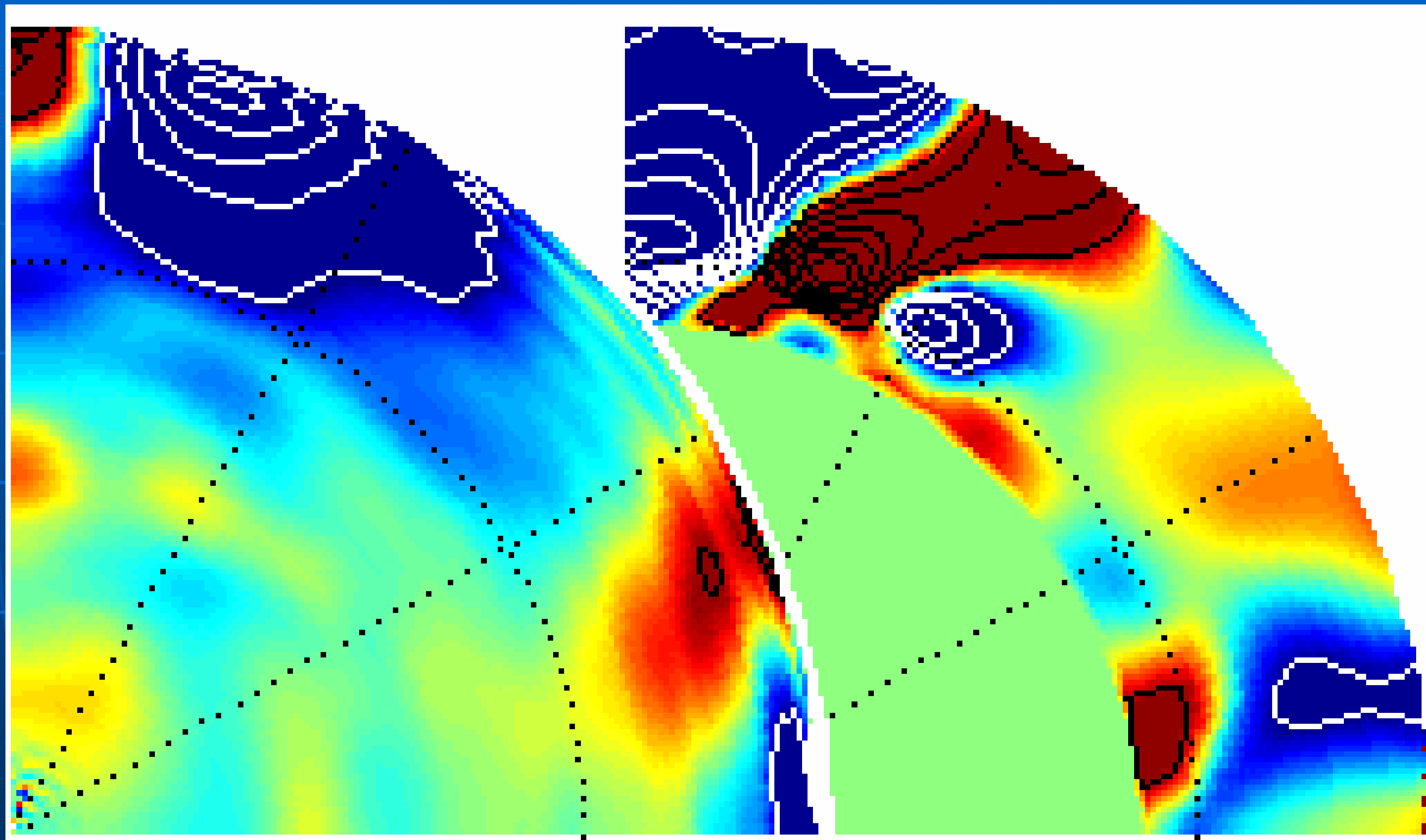
WSO MF Sun

Gavryuseva, 2006



Time, in years

Observed and modelled dynamics



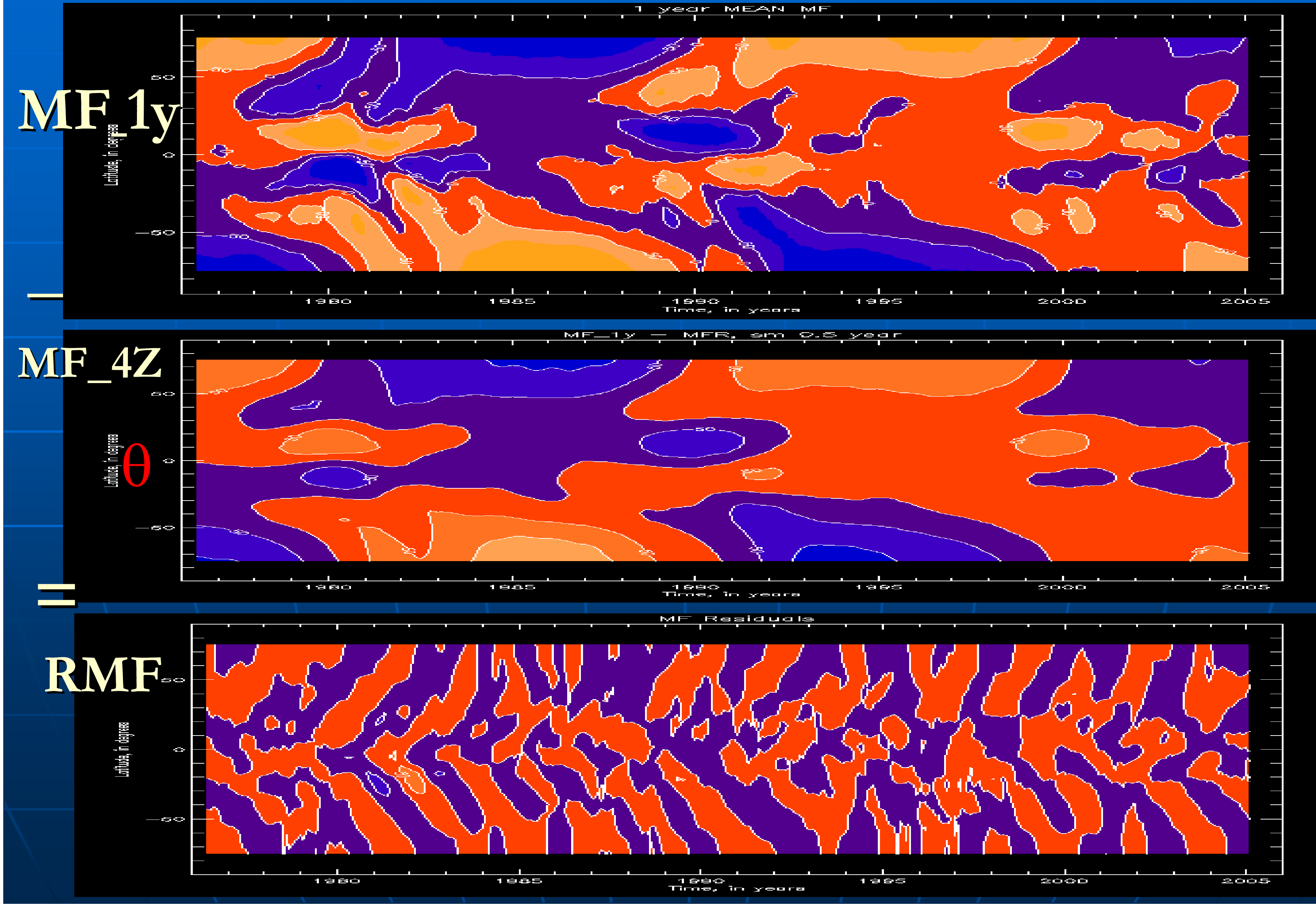
6 1/2 year MDI inversion, enforcing 11-yr periodicity

Vorontsov et al.

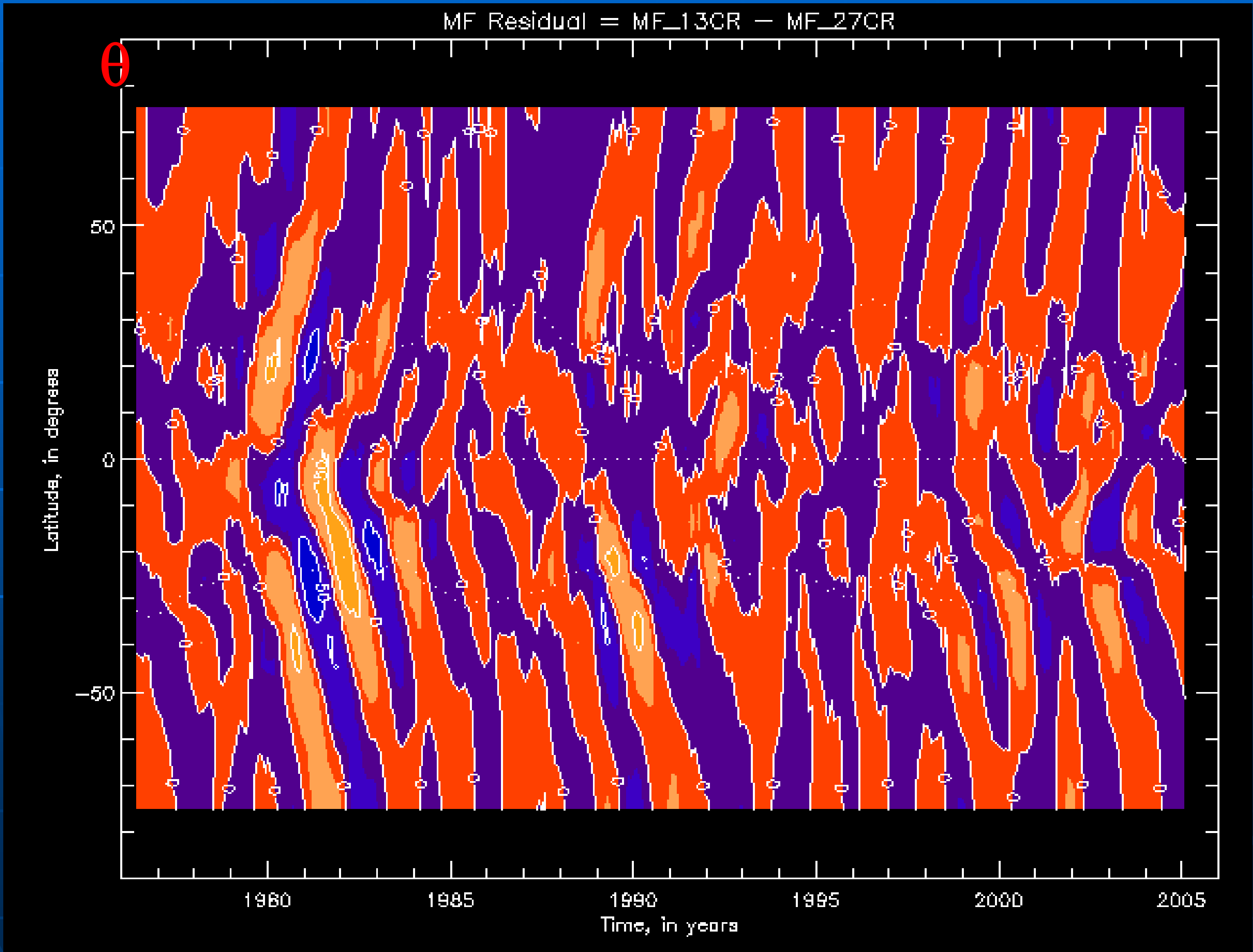
Non-linear mean-field solar dynamo models

Covas, Tavakol and Moss

MF_1y – MF_4zones = RMF



MFR = 1-year MF mean - 2-year MF mean



Velocity 40 km/h

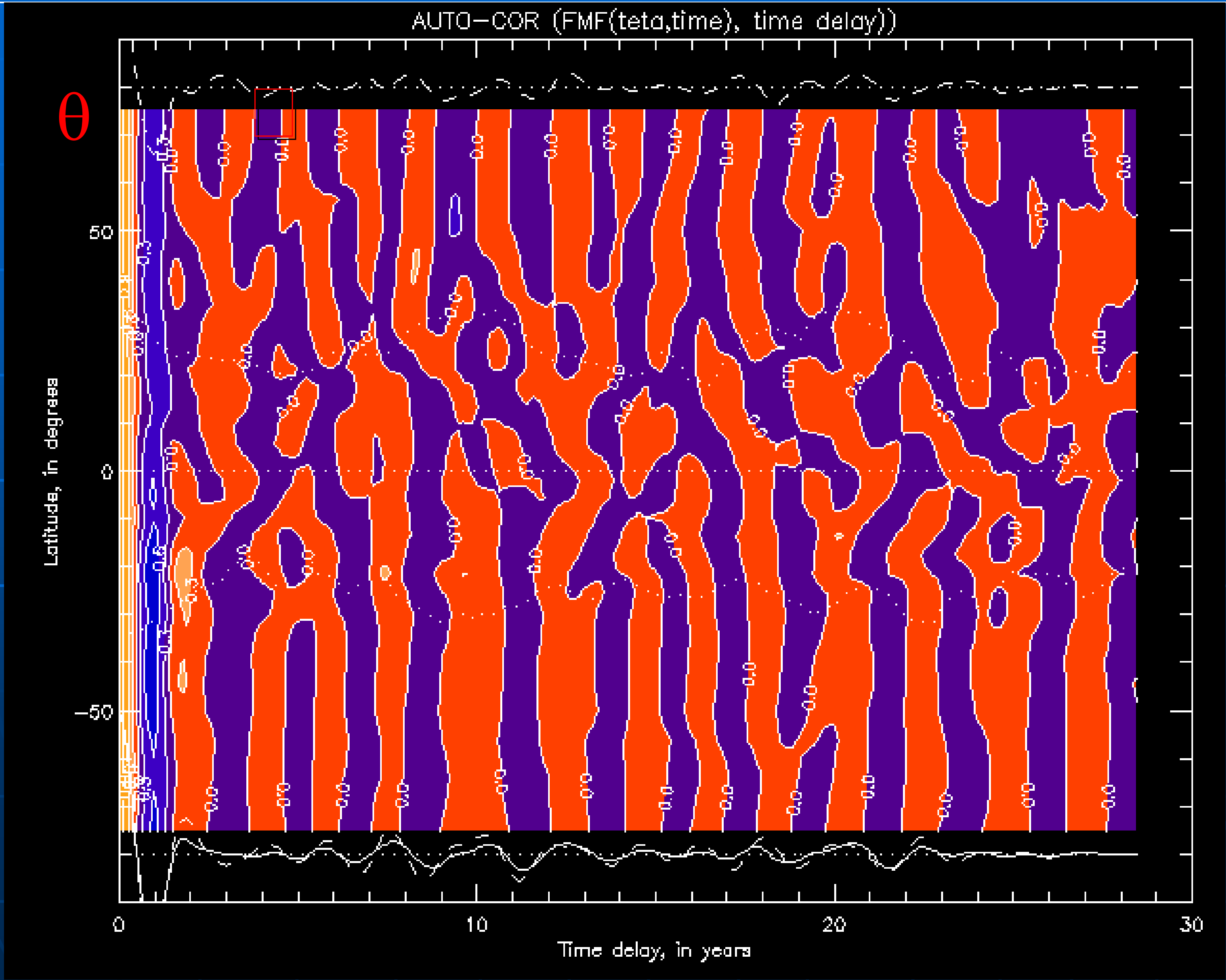
Interference of streams

Double Maxima

It takes 2-3 years to run from equator to pole

Time shift, in years

Auto-correlation of SMF Residuals

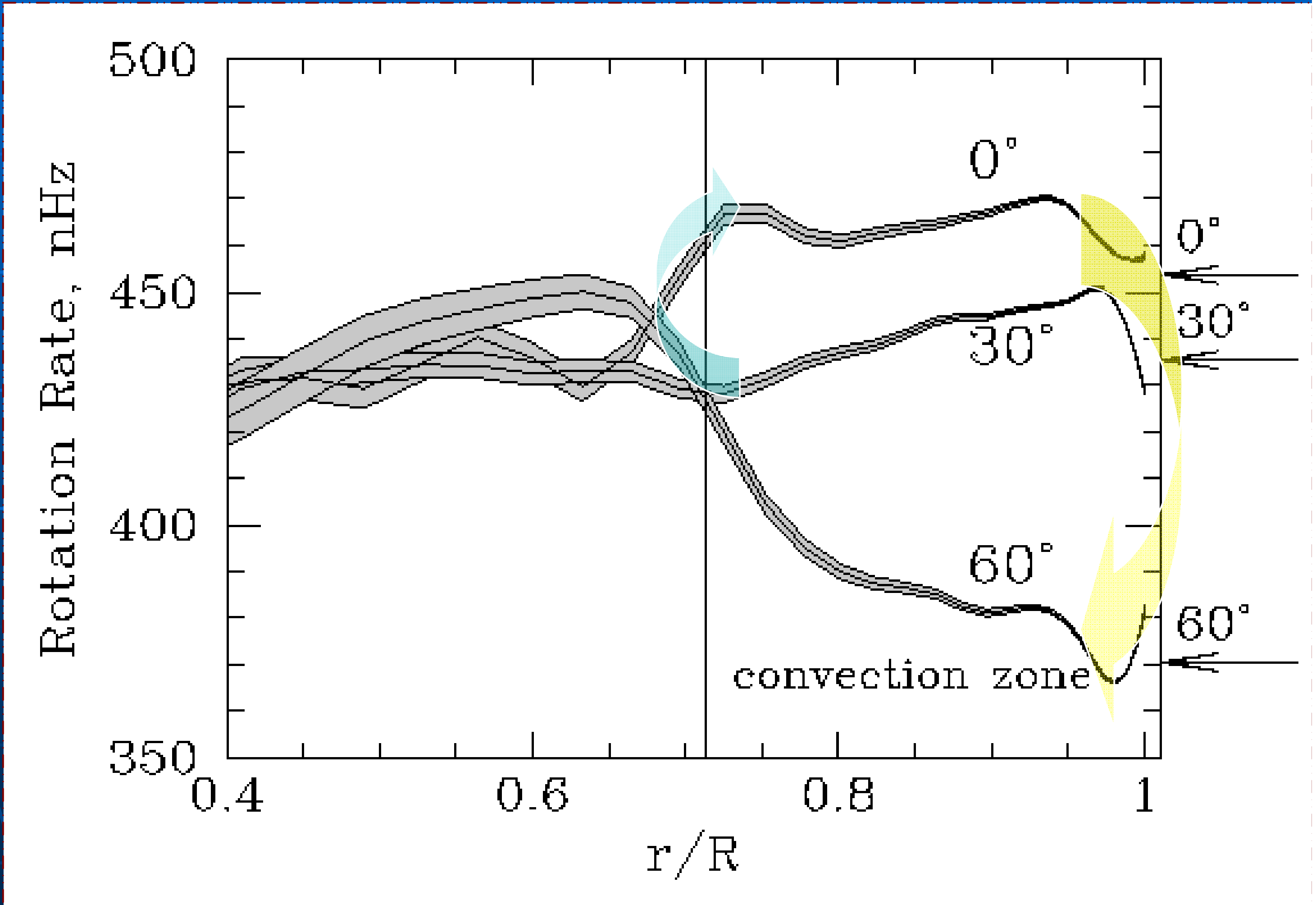


Quasi 2-3-year periodicity over all latitudes θ

Different in the Northern ans in the Southern Hemispheres

Internal differential rotation : tachocline

Large radial gradients in rotation rate at bottom of CZ (tachocline), but also just below solar surface (enigmatic).



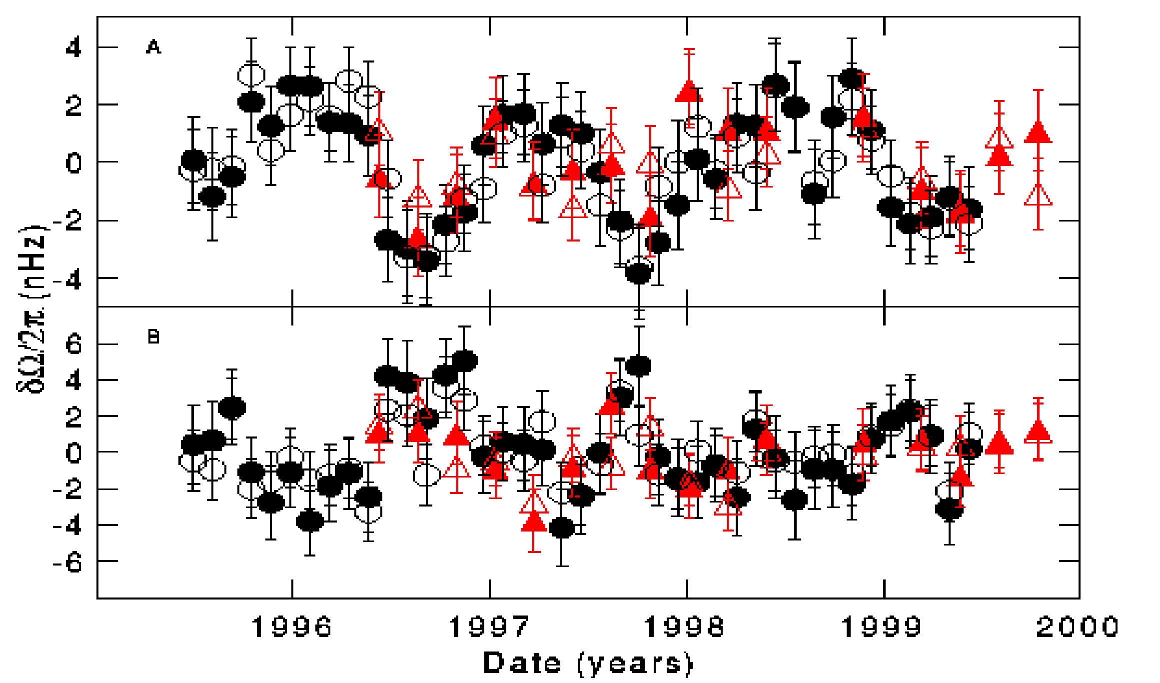
Direction of MF drift

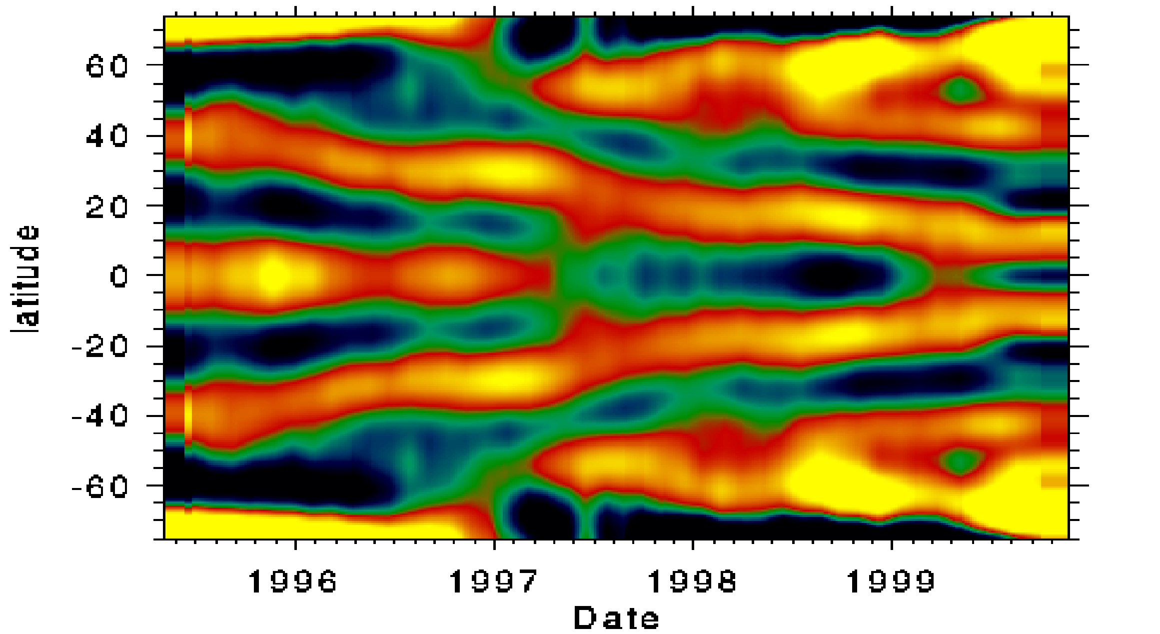
~ dΩ/dR * α

1.3 - year variability of solar rotation rate from GONG & MDI data at 0.99R Sun

- ● GONG-RLS
- ▲ MDI -RLS
- △ MDI -OLA

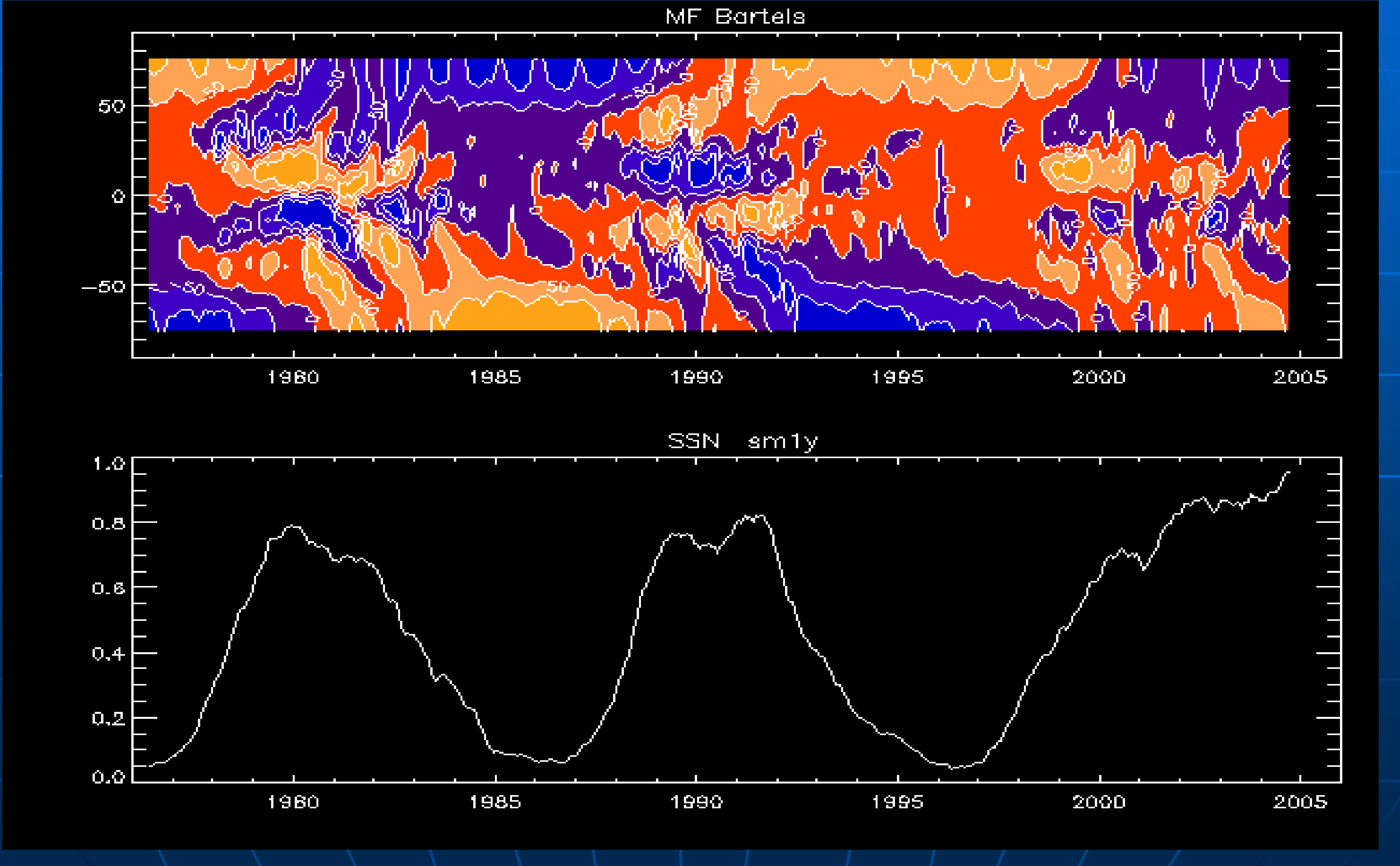
- 1.3 - year torsional waves of solar rotation rate from helioseismological data,
  R.Howe, 2006





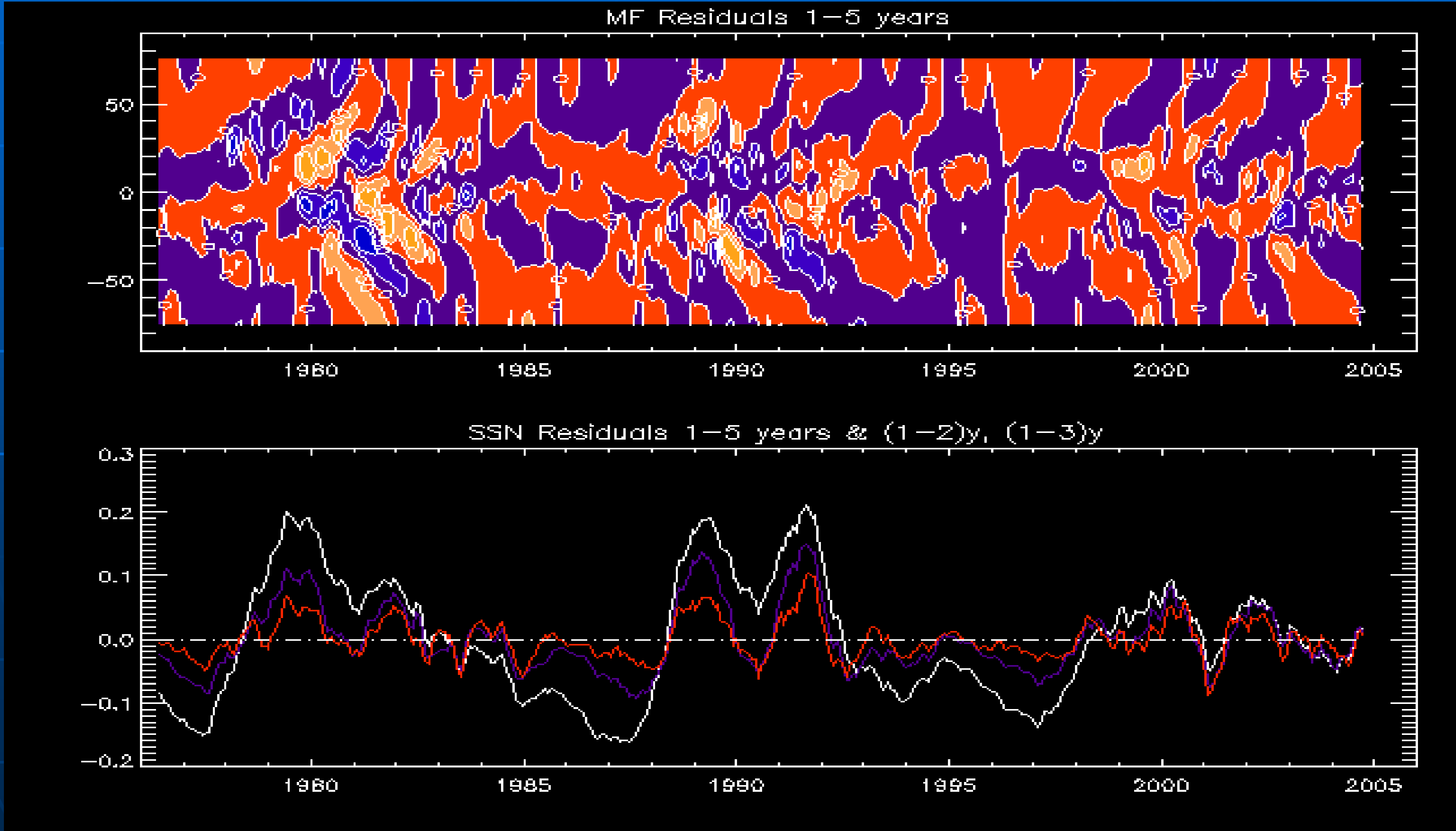
NSO/NSF

Photospheric magnetic field MF & Sunspot number as F(time)



Magnetic field MF residual

= MF mean_1y – MF mean_5y



The Thinkers of Hamangia

(Neolitic Statiette, 6000-5000 years BC)

ν_e

ν_μ

ν_τ

Periods, Frequencies, Amplitudes, Phases of the modes used for the phenomenological model of neutrino counting rate variability of the first 115 runs of Homestake measurements taken since 1970.281 to 1991.265

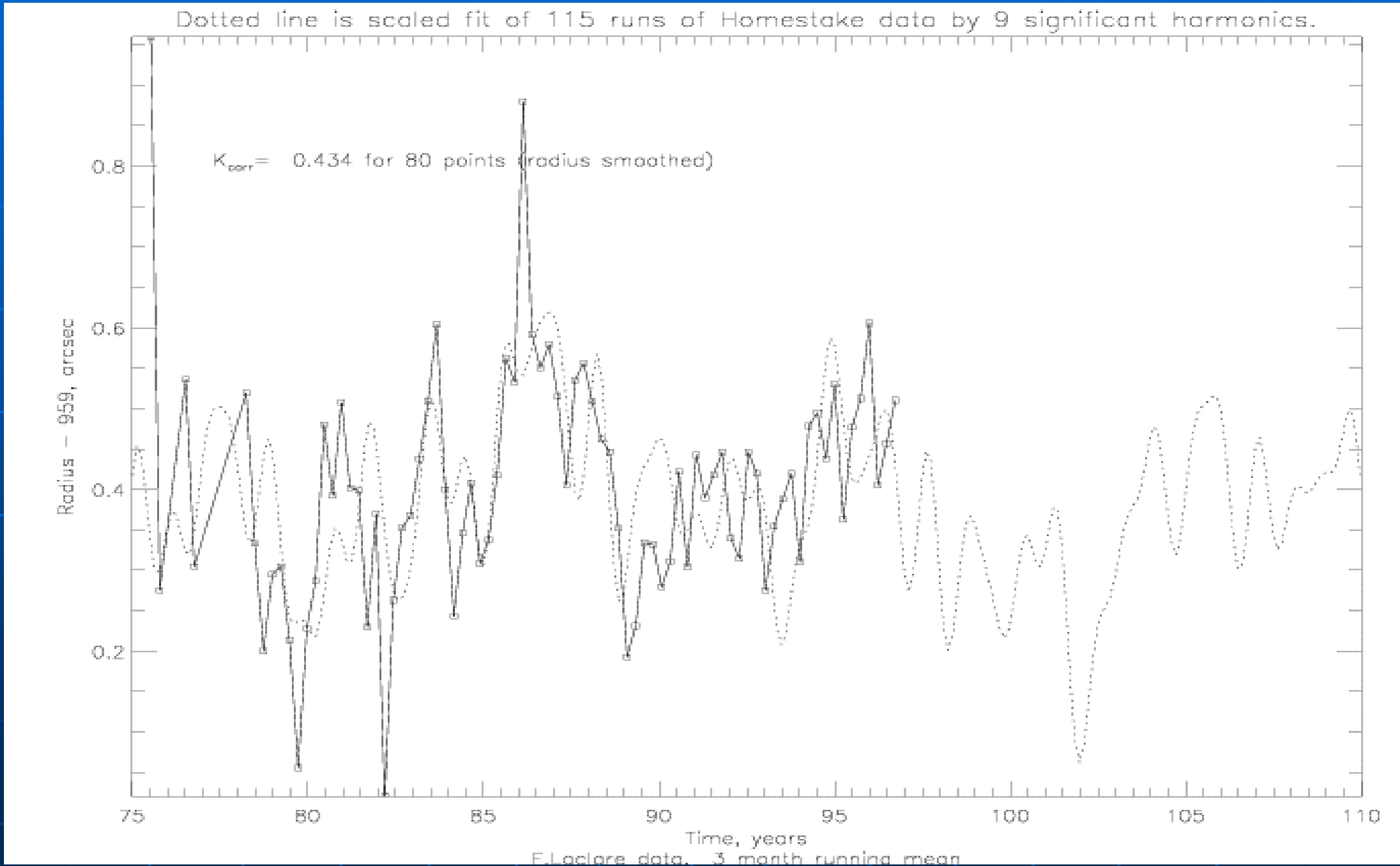
- 9 main harmonics of non-random origin

N	P, month	frequency	Amplitude	Phase	P, SuperKam	P GA LLEX	P SAGE
1	314.2,	3.1831E-03,	1.5082E-01,	2.252			
2	116.4,	8.5944E-03,	1.7402E-01,	2.443			
3	54.2,	1.8462E-02,	1.3045E-01,	3.021			48.7
4	33.8,	2.9603E-02,	1.0400E-01,	2.107	33.5		32.9
5	26.2,	3.8197E-02,	1.1680E-01,	.412	24.54	26.9	23.9
6	18.9,	5.2839E-02,	8.8069E-02,	-.822		18.7	18.7
7	15.9,	6.3025E-02,	9.5635E-02,	-1.896			15.9
8	14.3,	6.9710E-02,	6.9365E-02,	2.914	14.38		
9	11.3,	8.8808E-02,	7.6035E-02,	2.122	11.65		

Gavryuseva, et al., Solar Physics, 1991, 133, p.483
Gavryuseva E., et al., Astrophysical Journal, 1993, 407, p.805.

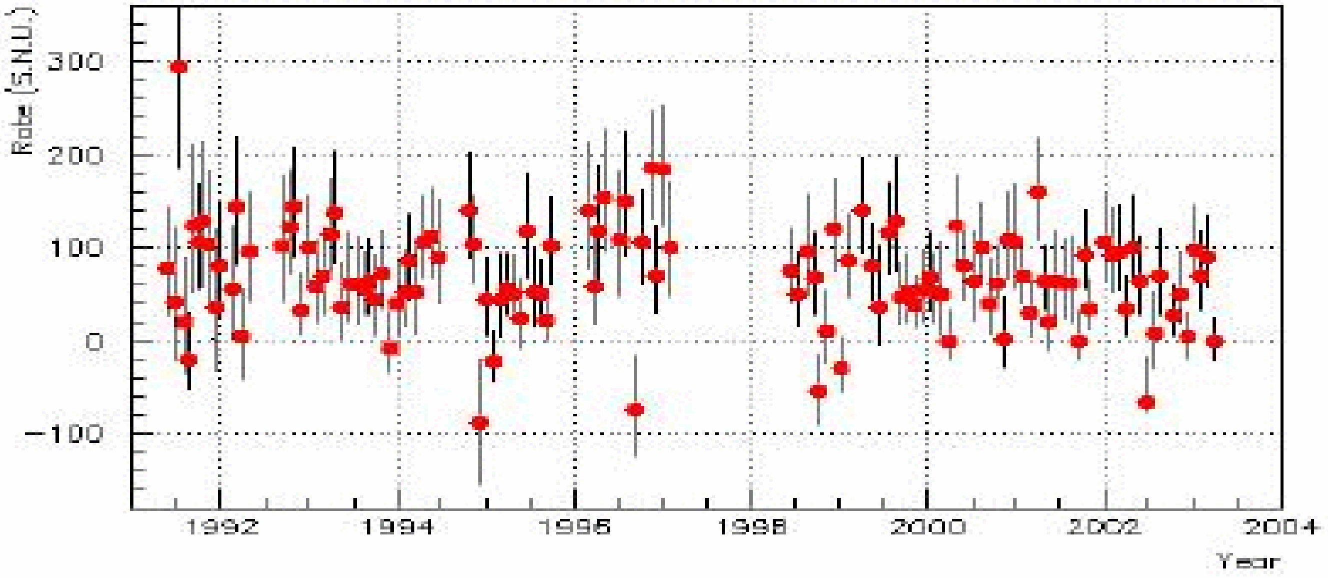
Sturrock P., Solar Phys., 2006, 239, p.1.
Raychaudhuri P., et al., 29th Int.Cosm.Ray Conf., 2005, 9 p.115

Model of neutrino counting rate variability & solar diameter



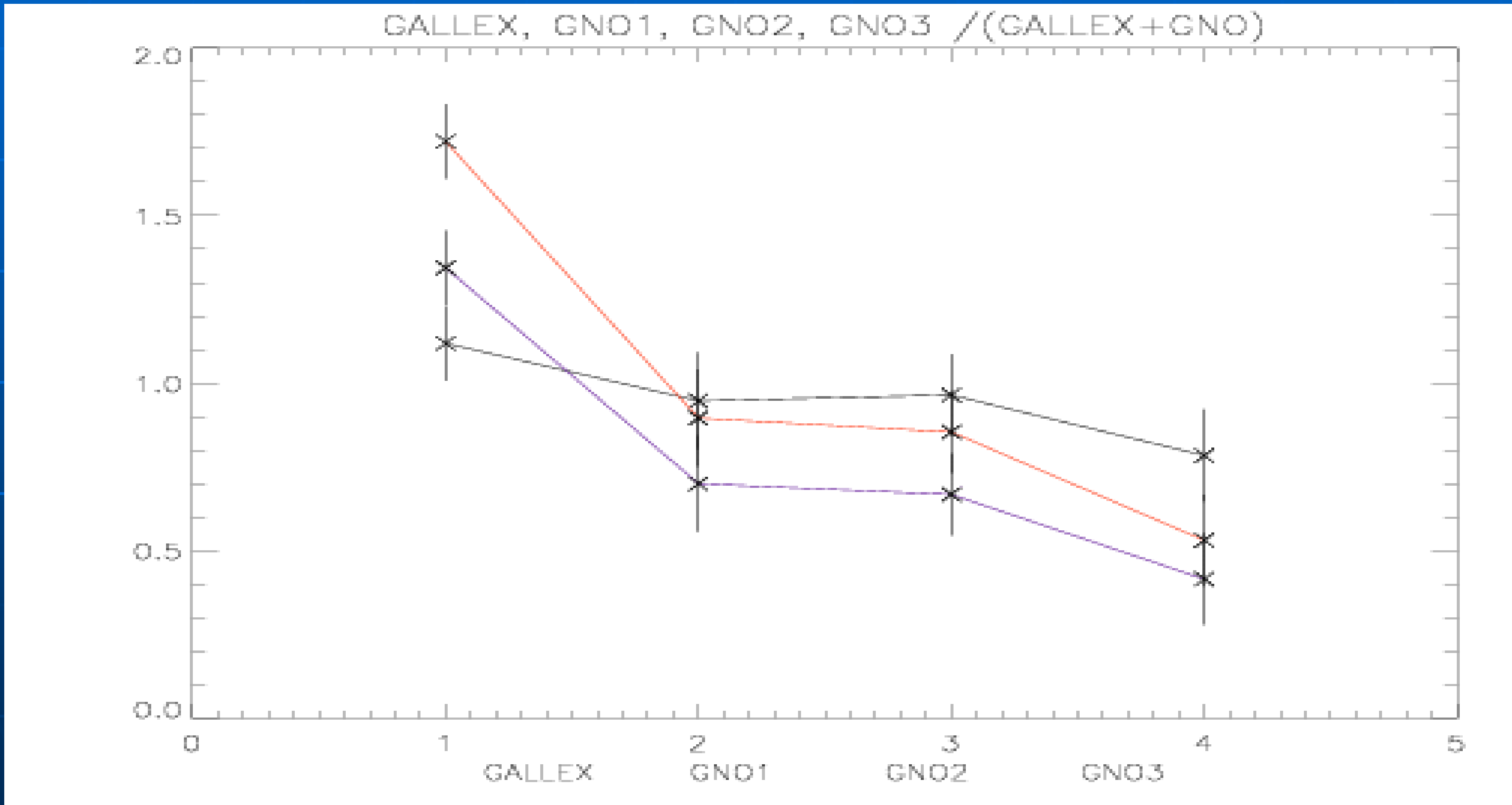
GNO and GALLEX results

Figure 4: Single run results for GNO and GALLEX [7] during a full solar cycle. Plotted is the net solar neutrino production rate in SNU after subtraction of side reaction contributions (see text). Error bars are $\pm 1\sigma$, statistical only.

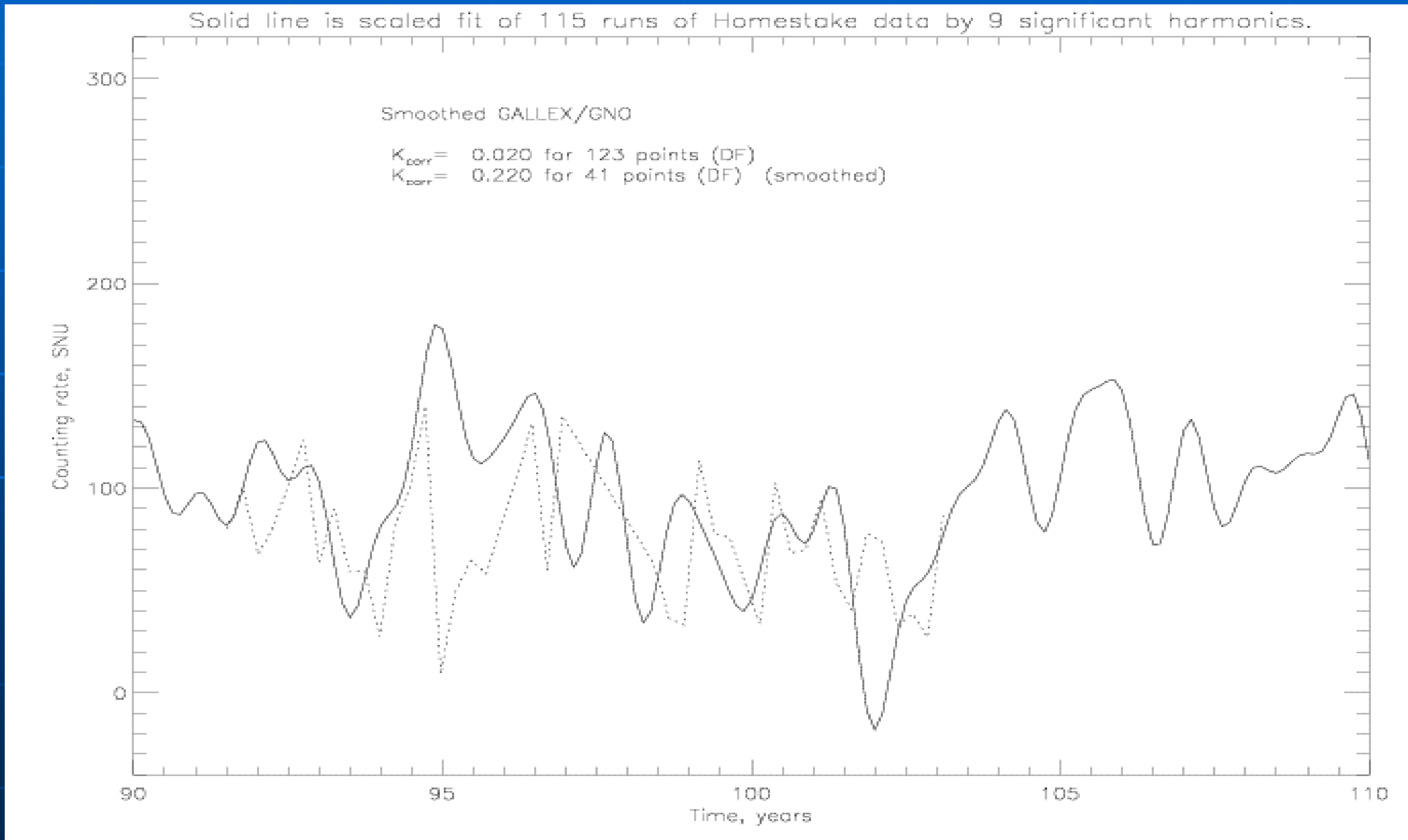


The scatter plots of the single run results for GNO, GALLEX and GALLEX+GNO are shown in Fig 5 (thick histograms). They are compatible with the Monte Carlo generated distributions of single run results for a constant production rate (62.9, 77.5 and 69.3 SNU respectively) under the typical solar run conditions (efficiencies, exposure time, etc.).

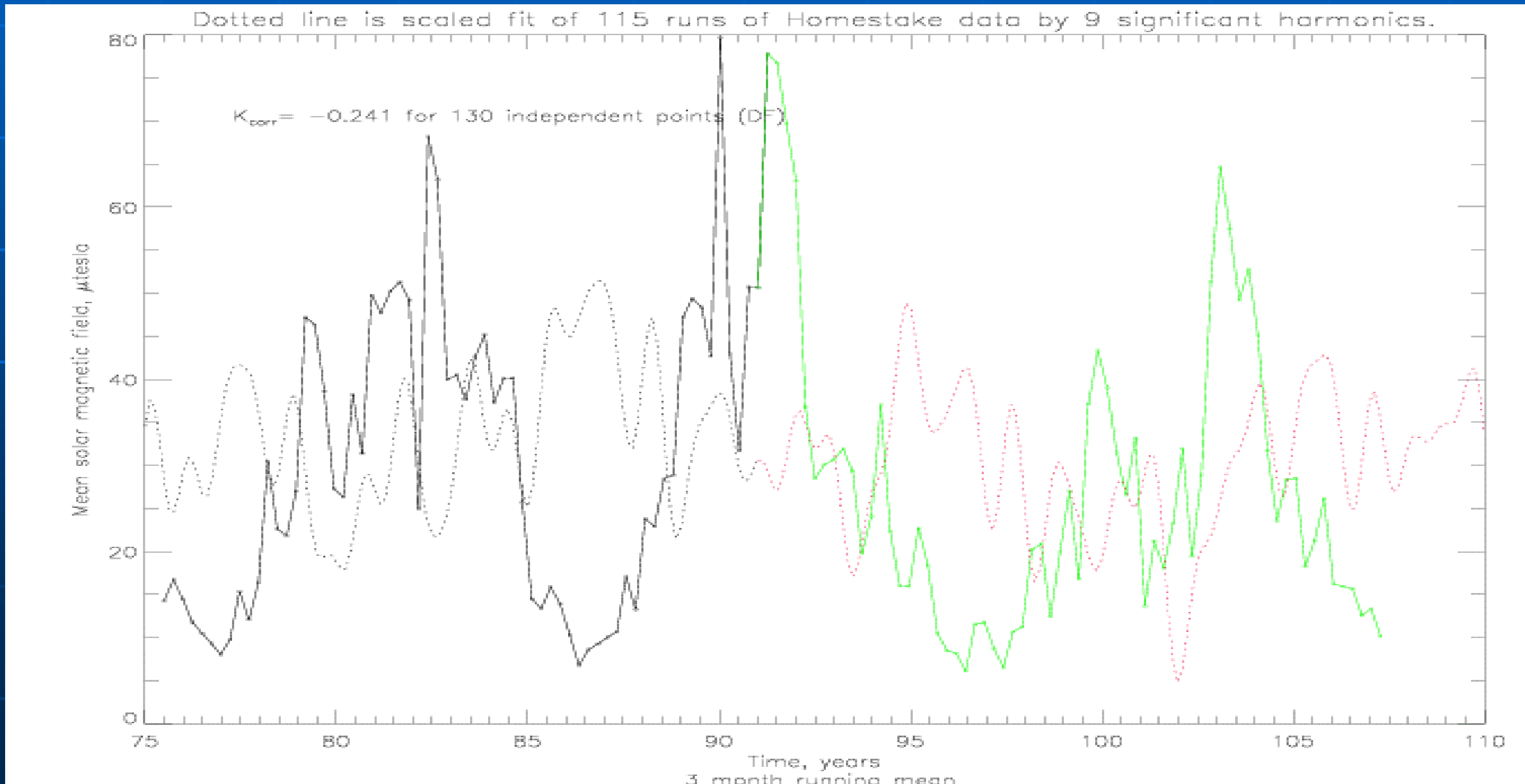
Neutrino counting rate in GALEX/GNO detectors & model



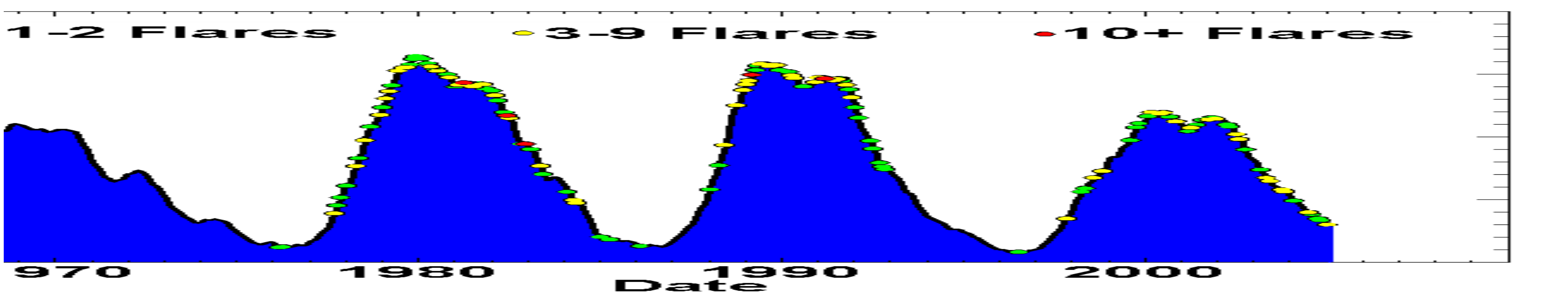
Neutrino counting rate in GALEX/GNO detectors & model

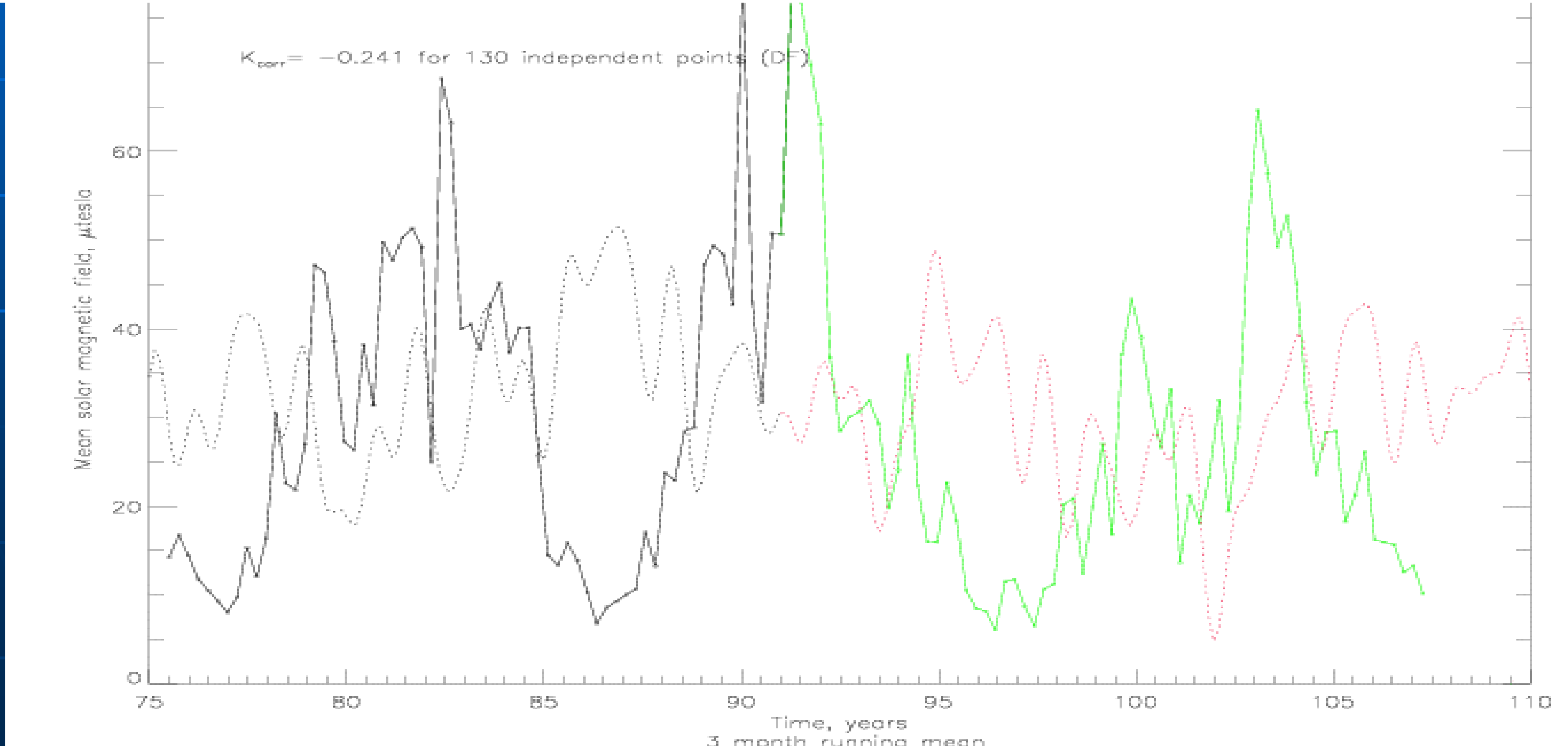


Intensity of mean magnetic field, model of neutrino counting rate variability (based on the data taken up to 1989) and predictions

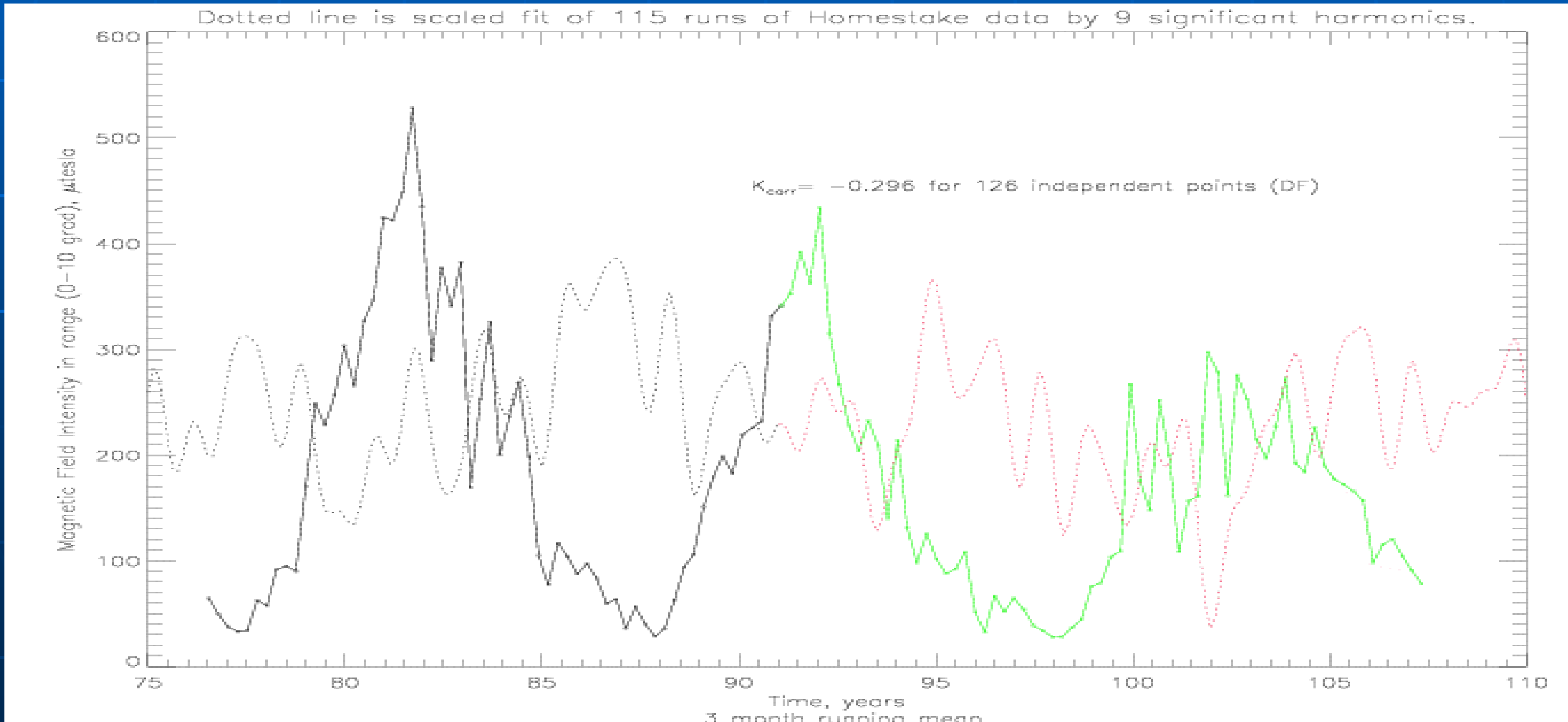


Model of neutrino counting rate variability and very big flares

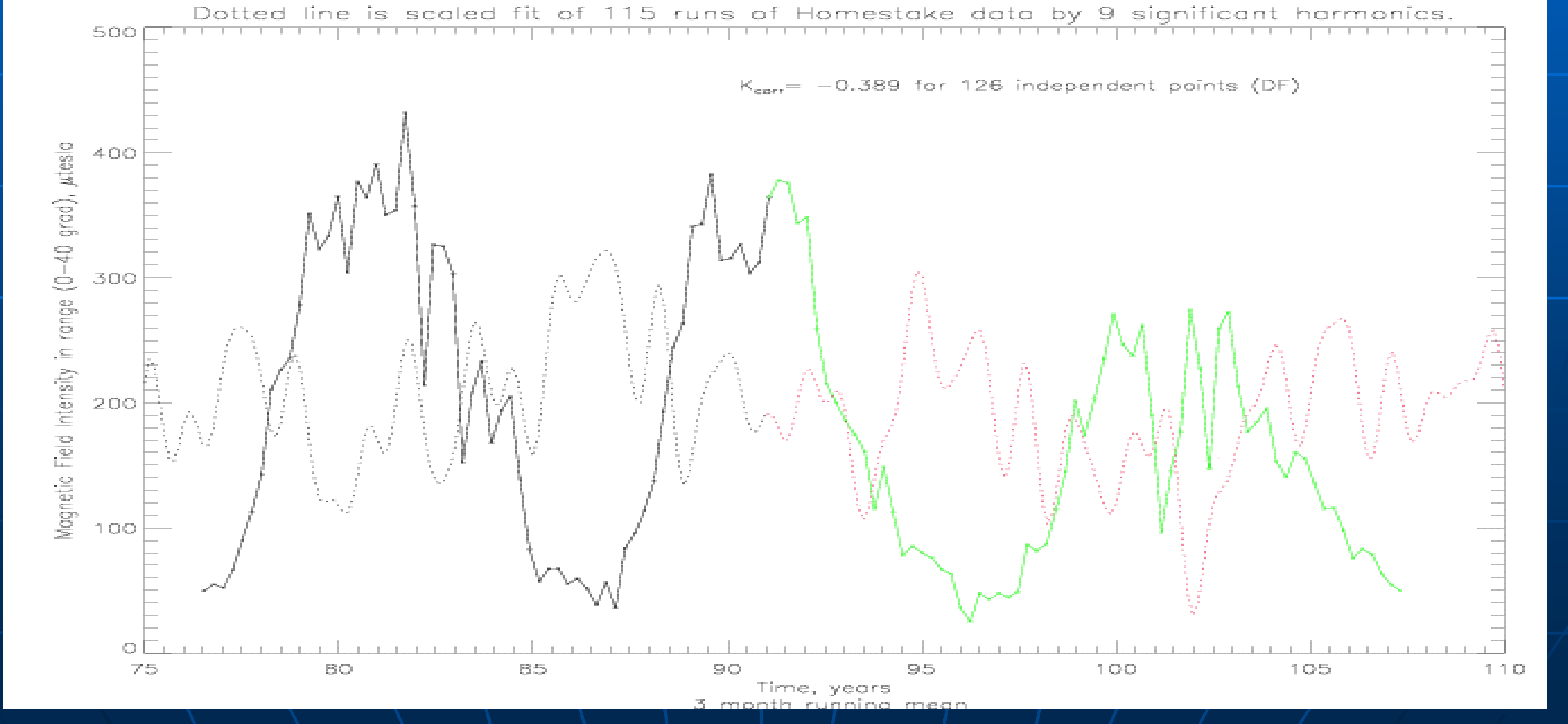




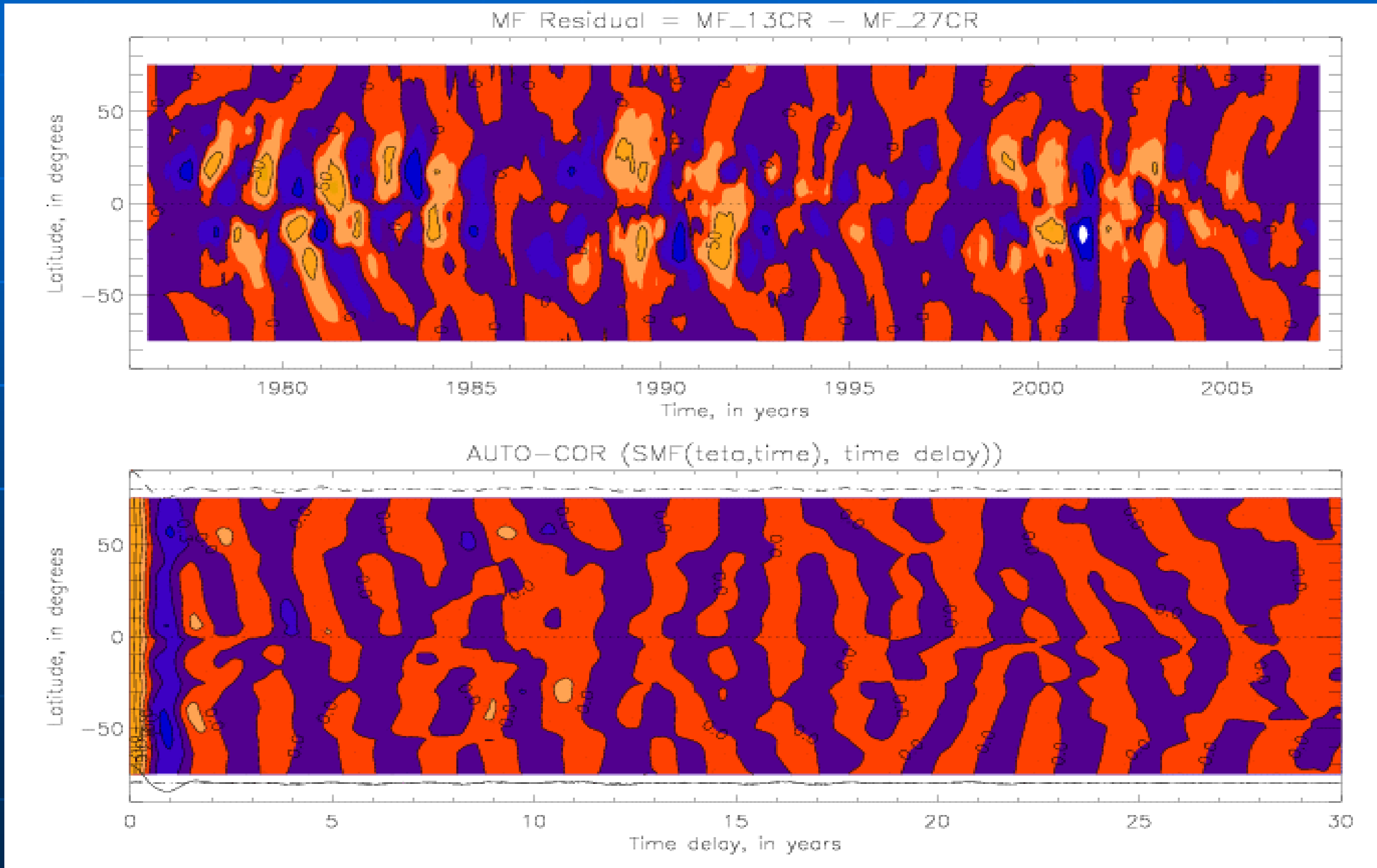
Intensity of magnetic field located at -9 < θ < 9 degrees & model of neutrino counting rate variability (based on the data taken up to 1989) and predictions



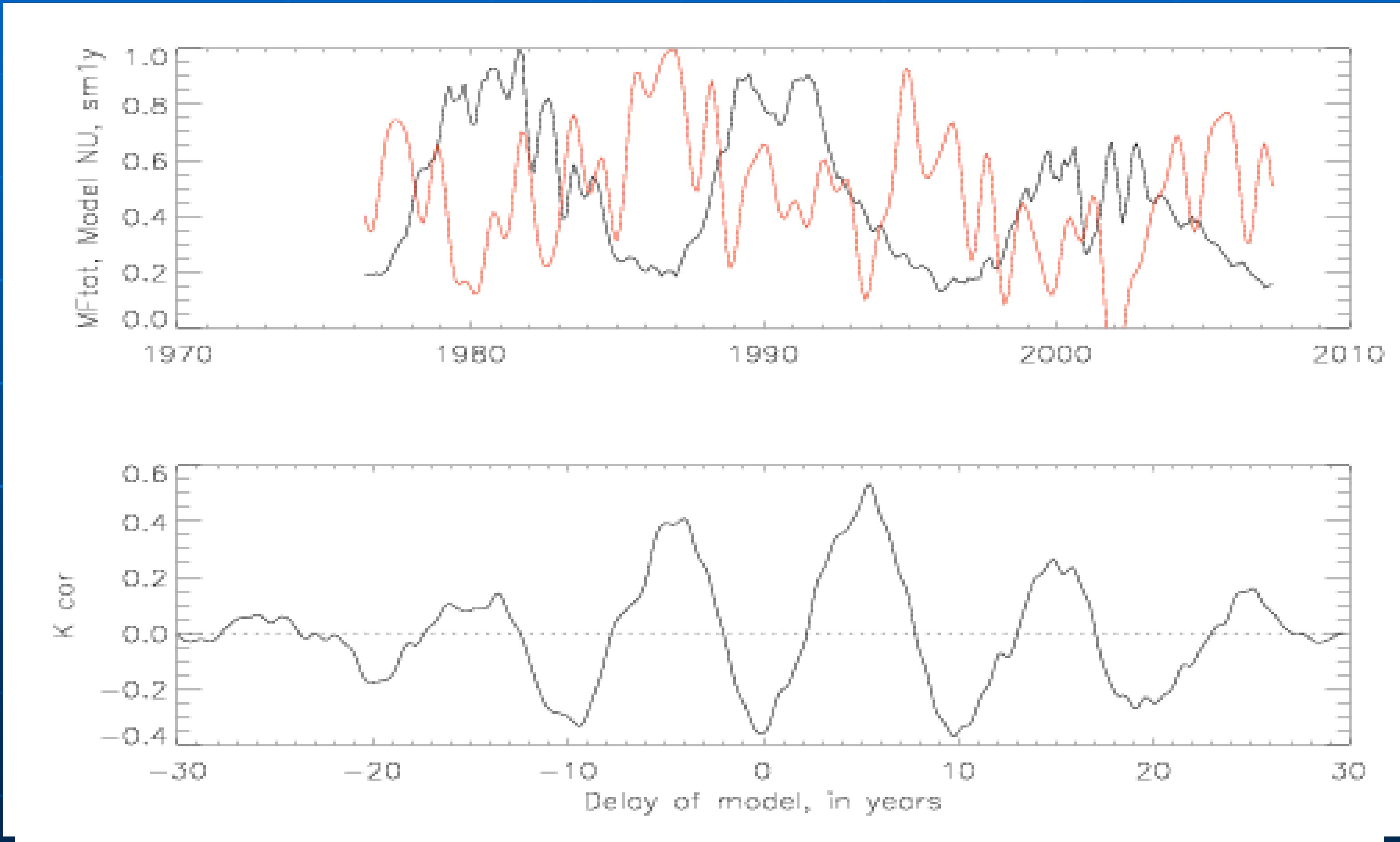
Intensity of magnetic field located at -40 < θ < 40 degrees & model of neutrino counting rate variability (based on the data taken up to 1989) and predictions



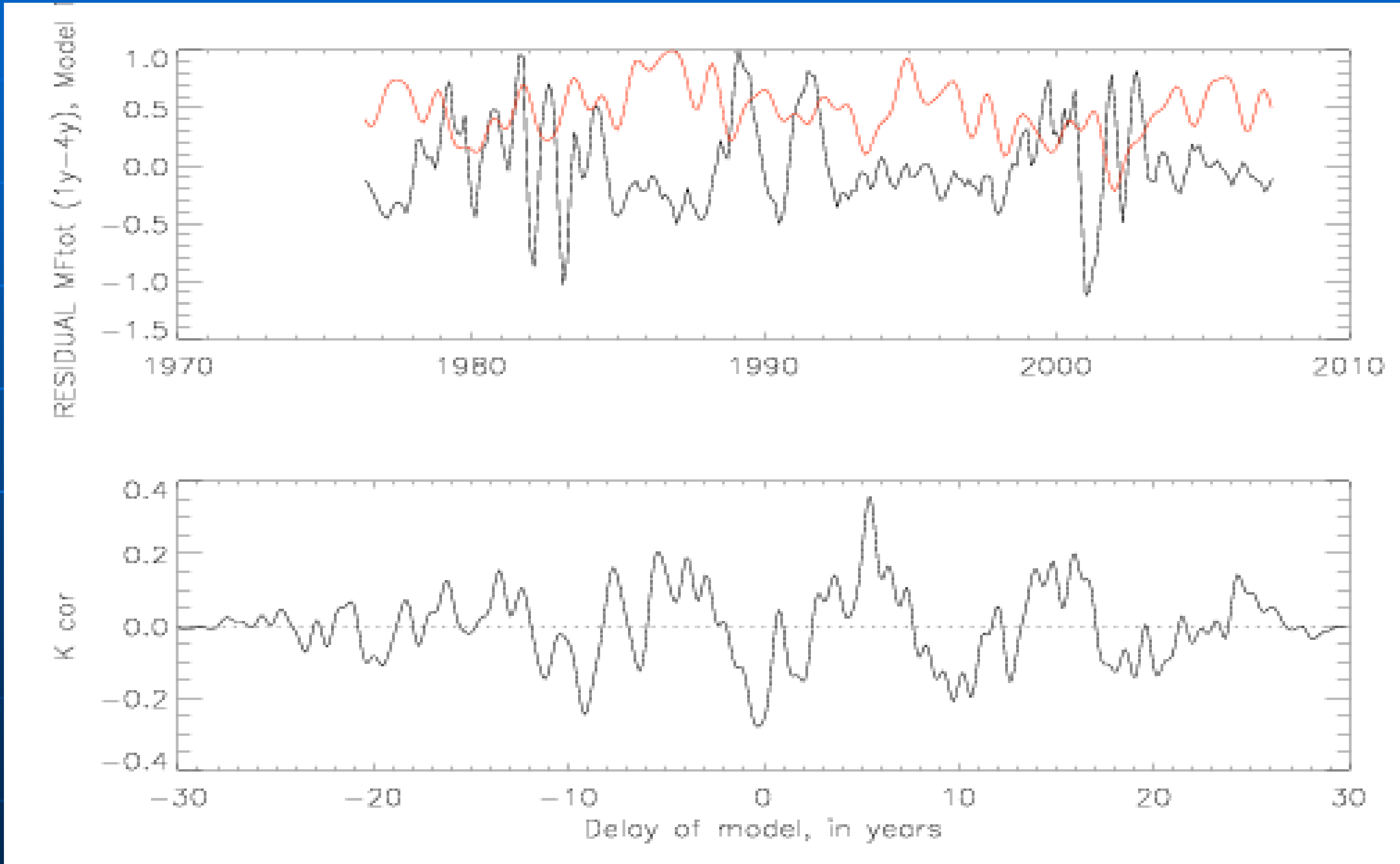
Residuals of MF intensity 1y-2y & K auto-correlation



Model & intensity of the total magnetic field & K autocor



Model & residuals of the total magnetic field intensity & K autocor



Conclusions and prediction

- Simple phenomenological model of neutrino counting rate variability (Mν) made in 1991
- Anti-correlates to Solar magnetic field on the long and short term scales
- Correlates to solar diameter
- Correlates to p-mode frequencies
- Predicts the variability around relatively high level of neutrino counting rate in 2007-2010.

Sight-seeing bus excursion in Moscow will depart from the entrance to the Faculty of Physics