

国家天文台青年学者学术交流活动第一期 11月03日

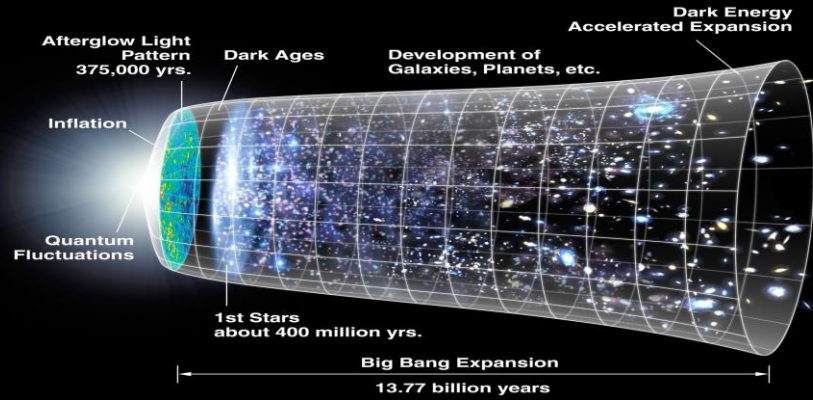
# Modeling Magnetic Helicity With Solar Cycles And Its Inspiration For Future Solar Magnetic Field Observations

杨尚斌

怀柔太阳观测基地

中国科学院国家天文台

# Background

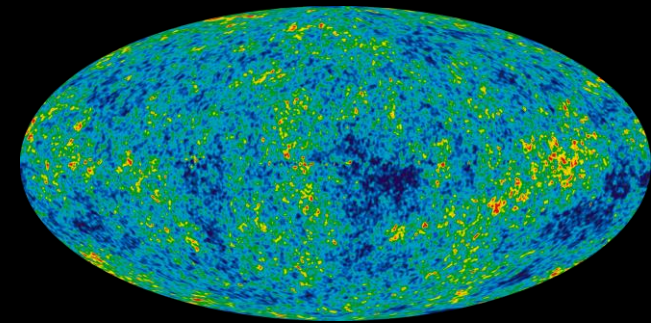


脉冲星

耀变星



微波背景辐射

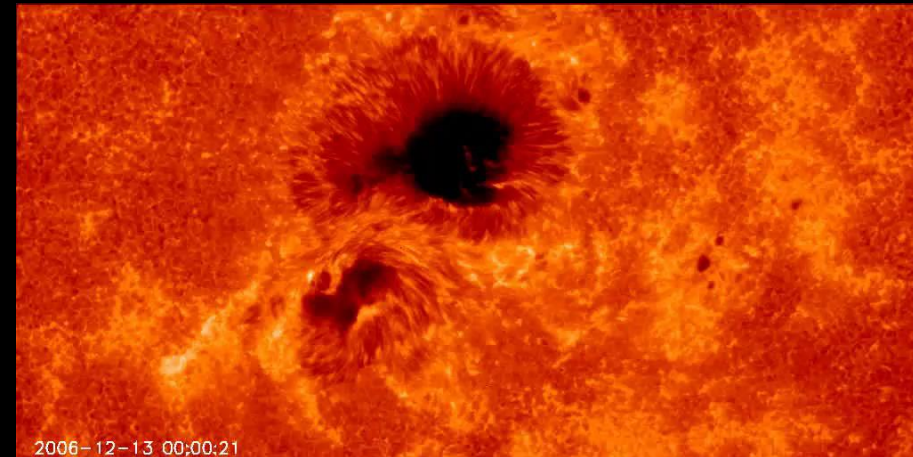
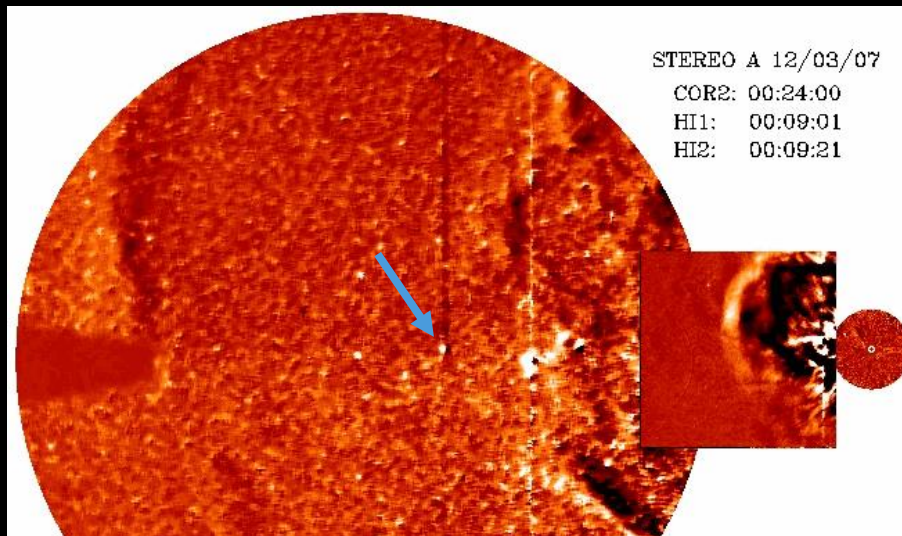


引力塑造了宇宙大尺度结构

电磁相互作用塑造了宇宙的活动性

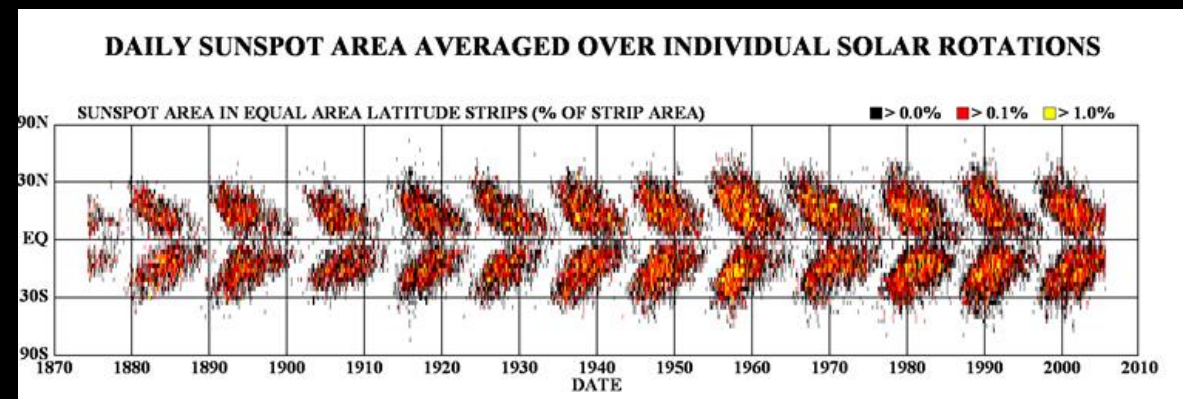
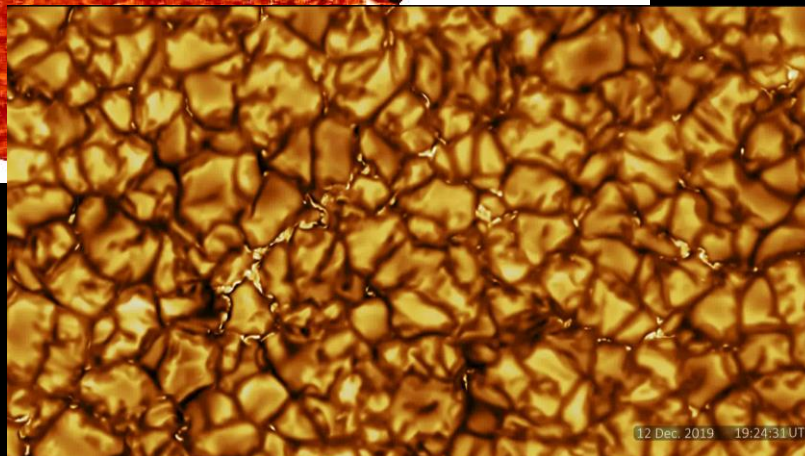
# Background

太阳物理的多时间尺度：可以展示从**毫秒**到**周年**尺度量级的动态演化过程



太阳耀斑

太阳11年活动周



太阳物理的多空间尺度：可以展示从**公里**到**AU**尺度量级的动态演化过程

# 《Science》杂志125个科学难题No.51:

## ➤ 驱动太阳的磁周期的是什么？

### Stretch-Twist-Fold Model



描述磁场的三维拓扑结构

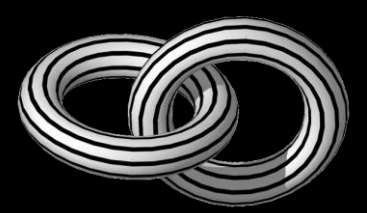
$$H_M = \int \mathbf{A} \cdot \mathbf{B} dV$$



$$H=0$$



$$H=T\Phi^2$$



$$H = \pm 2\Phi_1\Phi_2$$

太阳发电机过程：不同尺度下磁场和流场的耦合作用过程

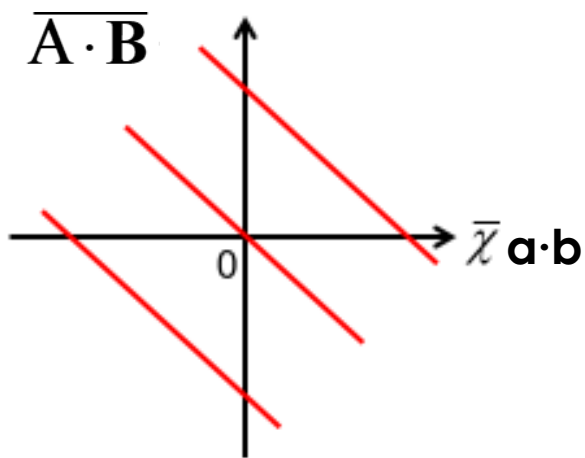
大磁雷诺数下的磁螺度守恒

太阳不同尺度上的磁螺度究竟是多少?  $\chi^{(\text{tot})} = ? (-, 0, +)$

总螺度=大尺度+小尺度

$$\chi^{(\text{tot})} = \bar{\mathbf{A}} \cdot \bar{\mathbf{B}} + \mathbf{a} \cdot \mathbf{b}$$

$$\bar{\mathbf{A}} \cdot \bar{\mathbf{B}} = -\mathbf{a} \cdot \mathbf{b} + \chi^{(\text{tot})}$$



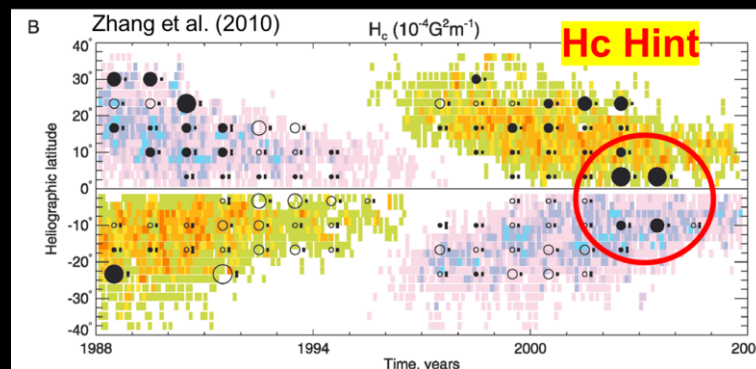
400 个活动区: 总螺度是零

**Table 1**  
Results of the Analysis Applied to the Timeseries of Figure 1

Figure	N	Hemisphere	$\Delta H_{m(+)}$ ( $\times 10^{44} \text{ Mx}^2$ )	$\Delta H_{m(-)}$ ( $\times 10^{44} \text{ Mx}^2$ )	$\varepsilon_{H_m}$	Differential Rotation?
1(a)	393	Both	5.37	-5.45	-0.0076	YES
1(b)	197	Northern	0.9	-4.23	-0.65	YES
1(c)	196	Southern	4.47	-1.22	0.57	YES
1(d)	393	Both	4.12	-4.28	-0.019	NO
1(e)	197	Northern	1.66	-2.53	-0.21	NO
1(f)	196	Southern	2.46	-1.75	0.17	NO

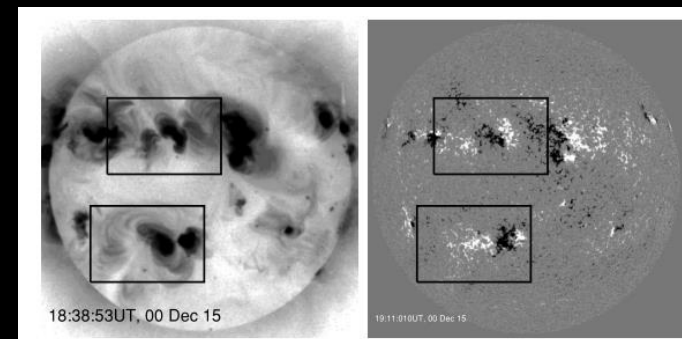
Gregolious et al. 2009

无力场参数统计 Not Zero



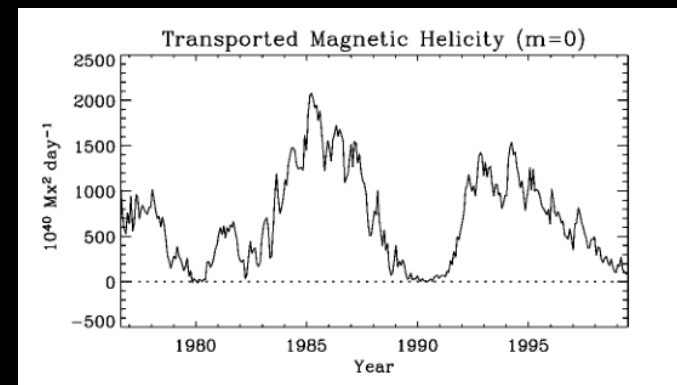
Zhang et al. (2010)

大尺度X射线环: Not Zero



Zhang et al. 2010

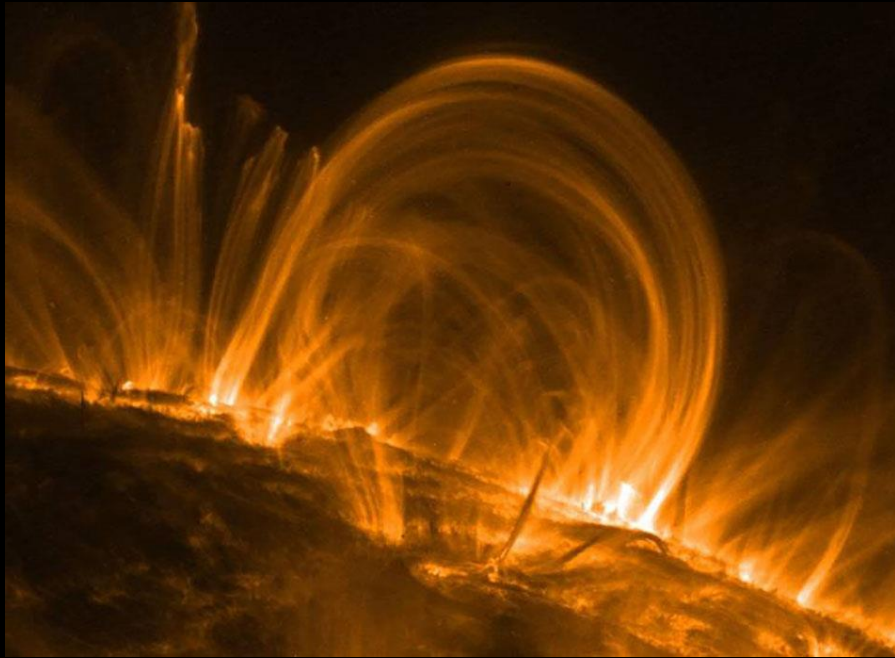
北负南正 Zero



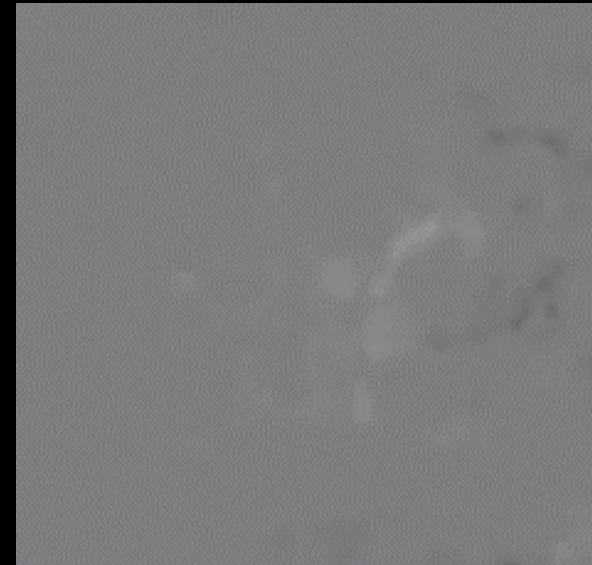
Berger and Ruzimaikin 2000

# 磁螺度传输计算方法

三维磁场无法直接测量



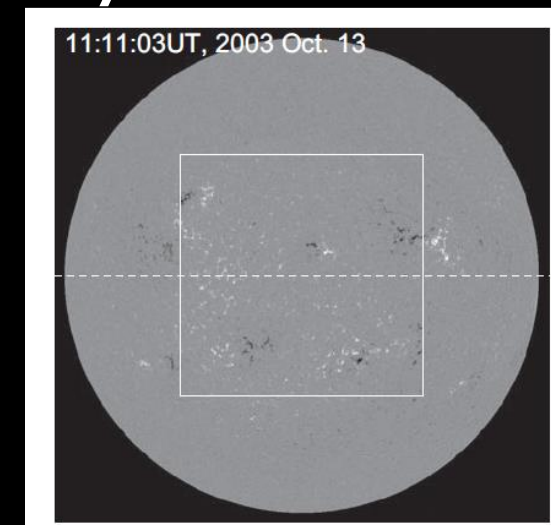
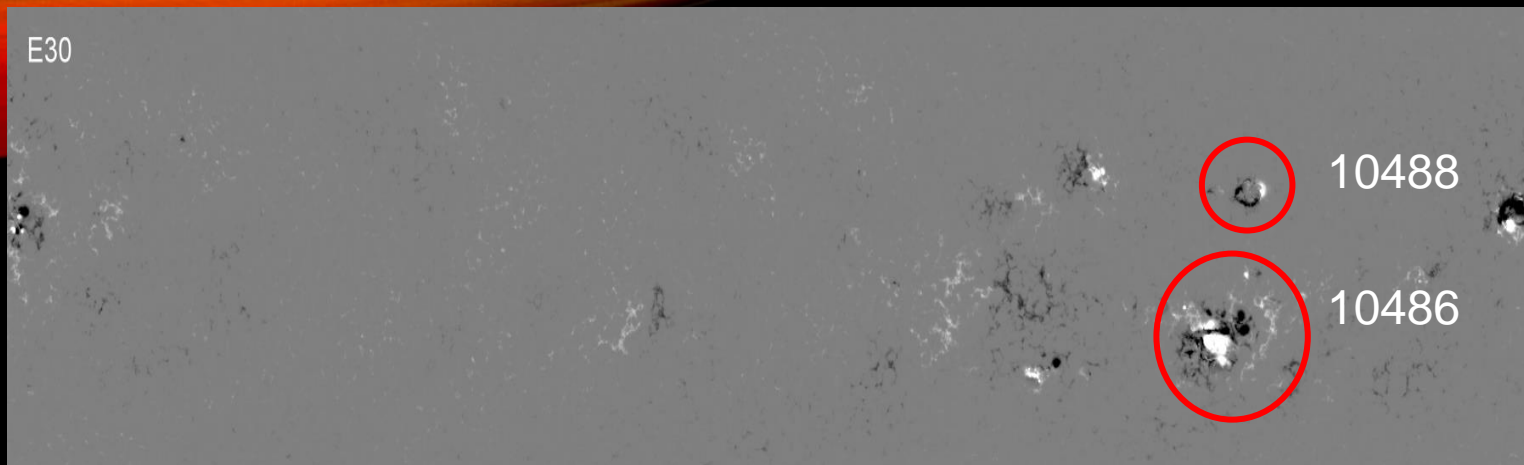
TRACE 卫星的极紫外磁环观测



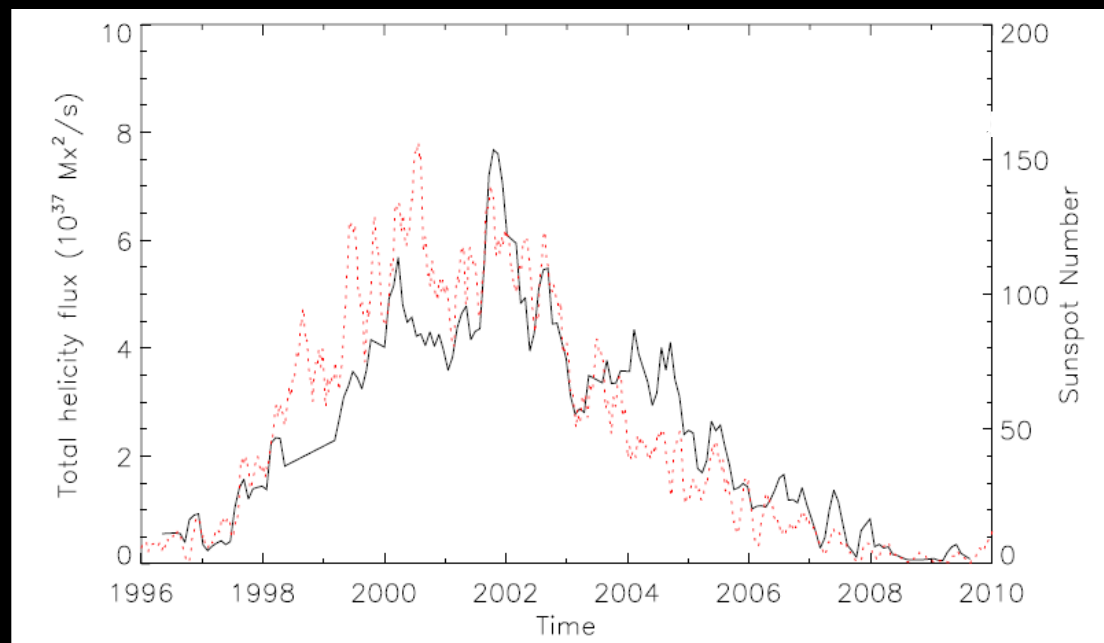
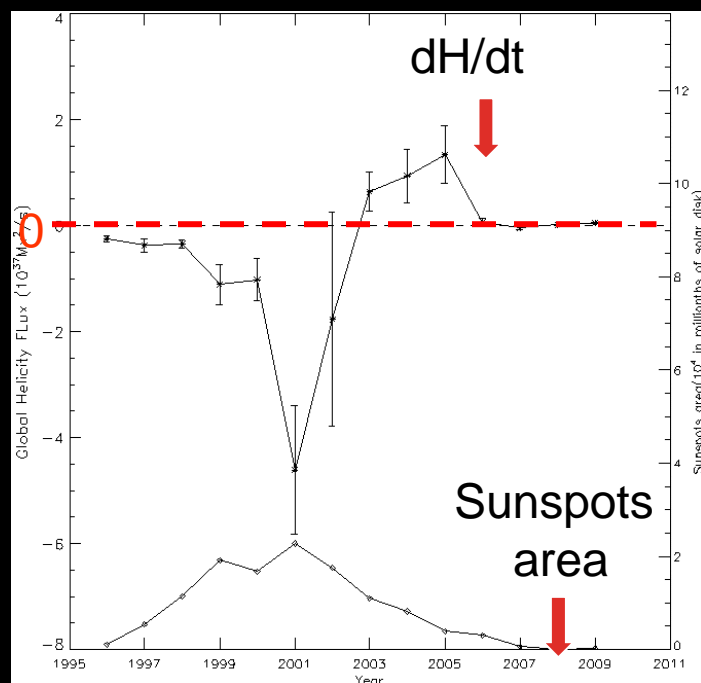
$$\frac{dH_R}{dt} = -2 \int (\mathbf{A}_p \cdot \mathbf{U}_{LCT}) \mathbf{B}_z dS$$

$$H = \int \frac{dH}{dt} dt \quad (\text{Chae et al. 2001})$$

# Imbalance of magnetic helicity with solar cycles-23 solar cycle



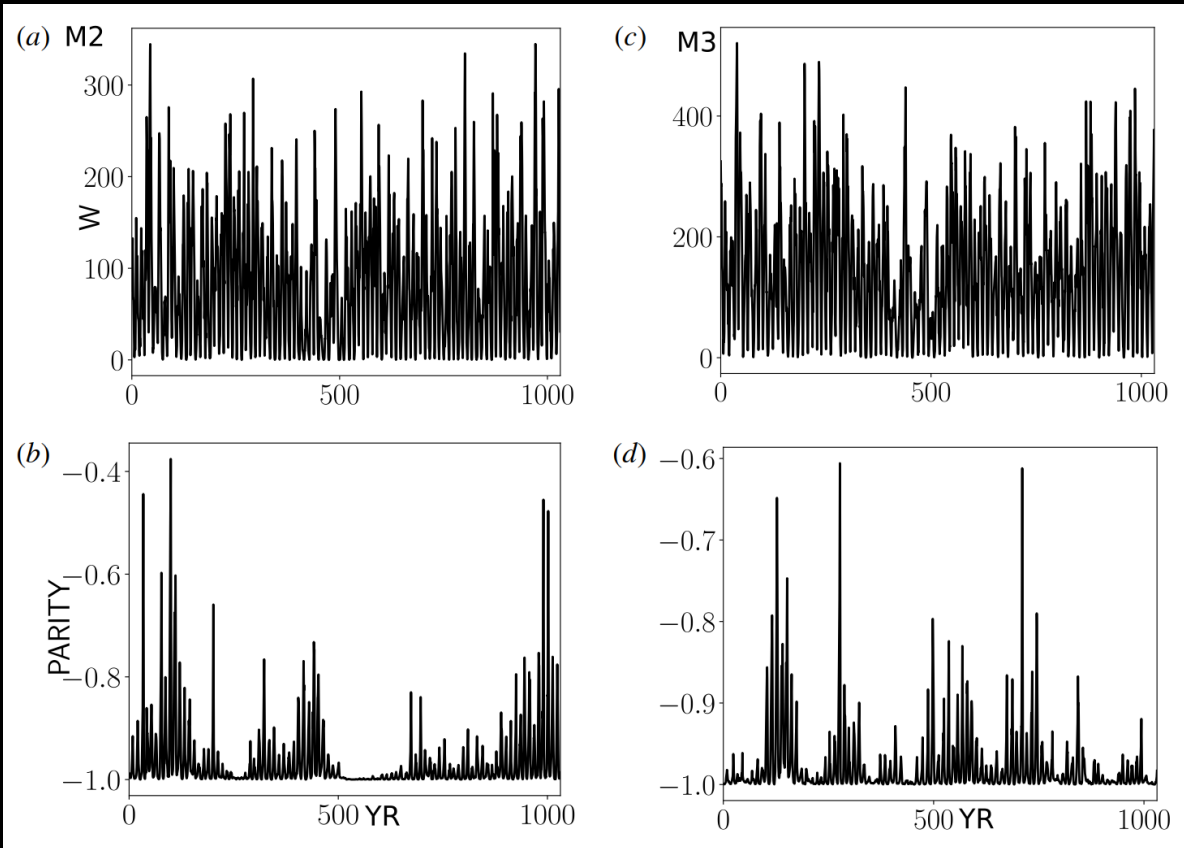
MDI (1996-2009)



Solar Cycle

# 磁螺度守恒约束的平均场发电机模型

磁螺度守恒的时标从单个活动周扩展到多个活动周



$$\frac{\partial \bar{\chi}^{(\text{tot})}}{\partial t} = -\frac{\bar{\chi}}{R_m \tau_c} - 2\eta \bar{\mathbf{B}} \cdot \bar{\mathbf{J}} - \nabla \cdot \mathbf{F} - \frac{\tau_\xi(r)}{\tau_{0r}} \sin^2 \theta (\xi^{(\chi)}(t, \theta) \bar{\chi} + \xi^{(m)}(t, \theta) \bar{\chi}^{(m)})$$

$$\alpha_{ij} = C_\alpha (1 + \xi^{(\alpha)}(t, \theta)) \alpha_{ij}^{(H)} + \alpha_{ij}^{(M)},$$

模型参数

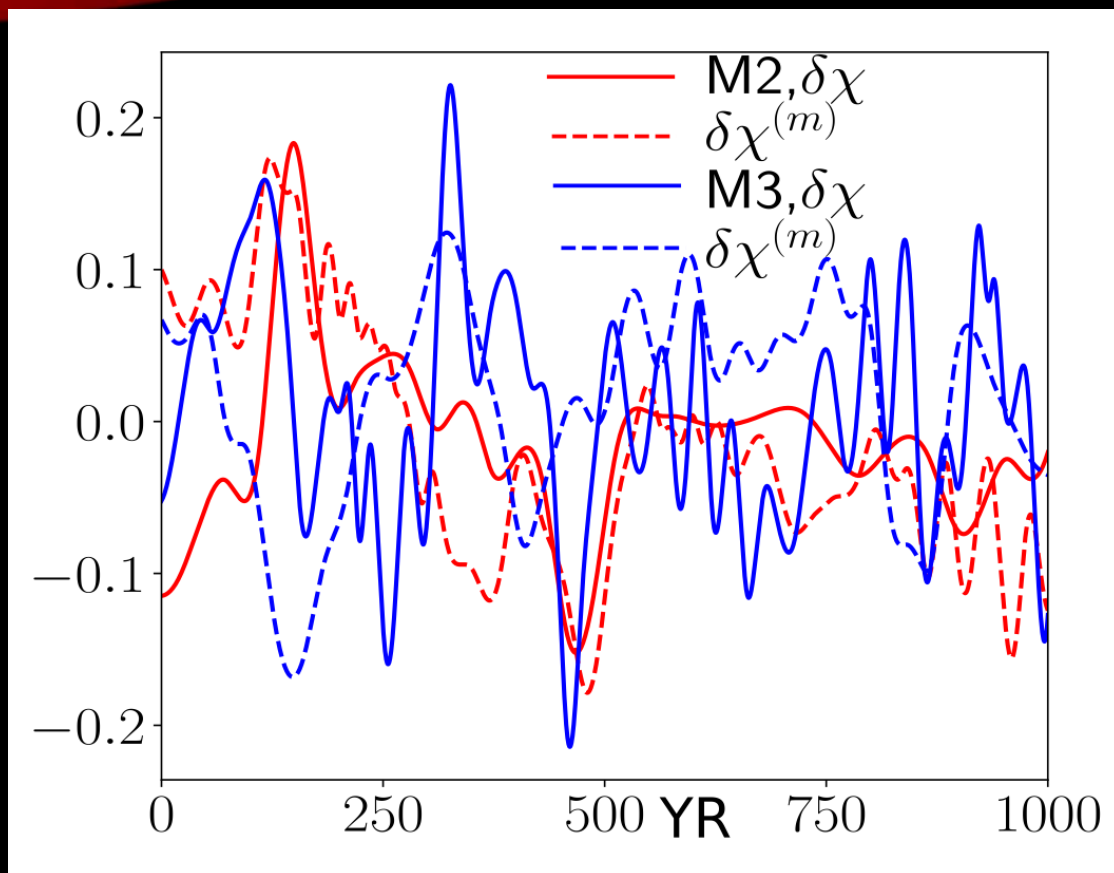
Model	$\xi^{(\alpha)}$	$\xi^{(\chi)}$	$\xi^{(m)}$
M1	Yes	No	No
M2	$\langle \xi^{(\alpha)} \rangle$	No	Yes
M3	$\langle \xi^{(\alpha)} \rangle$	Yes	No
M4	$\langle \xi^{(\alpha)} \rangle$	Yes	Yes

复现了太阳黑子相对数的变化和南北半球不对称性的演化

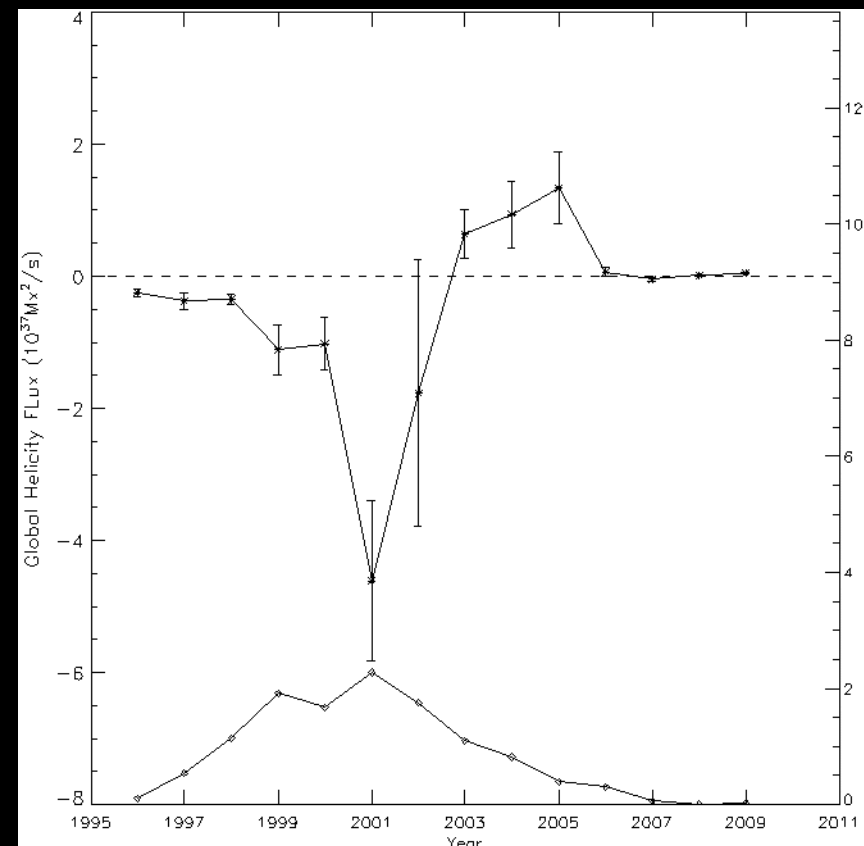
Yang, Pipin, Sokoloff et al. 2020, Journal of Plasma Physics



## Model Simulation



## Observation

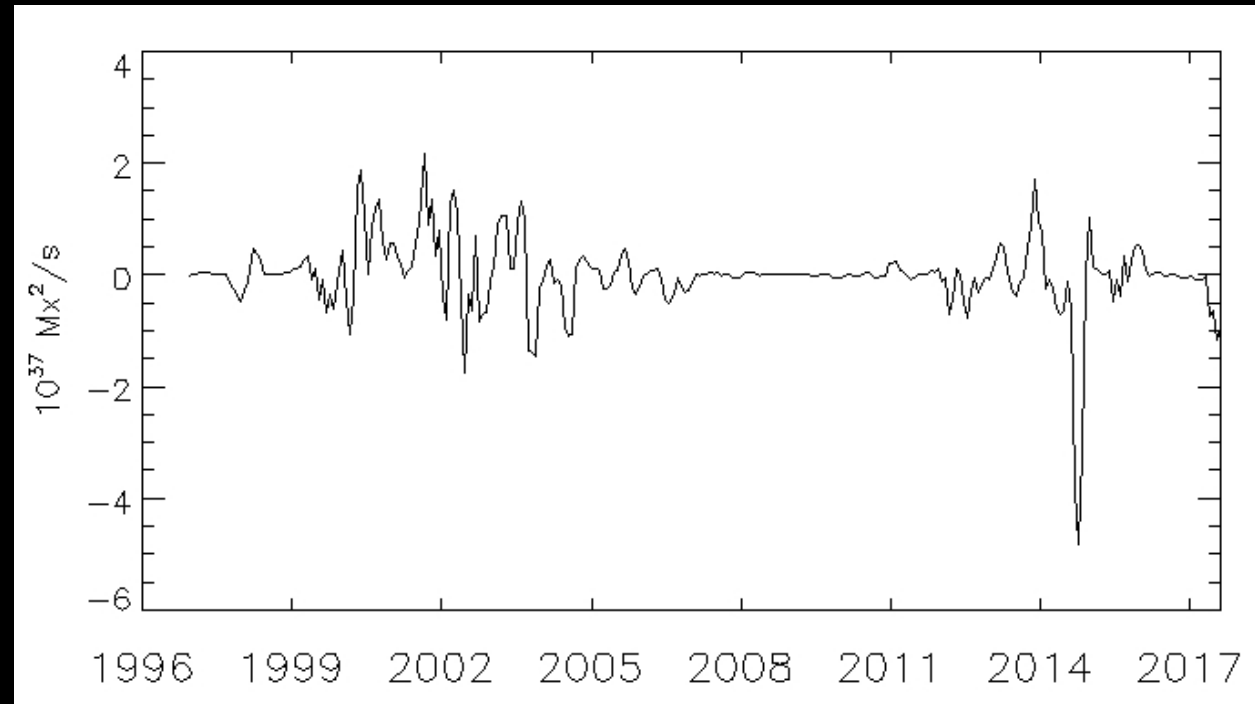
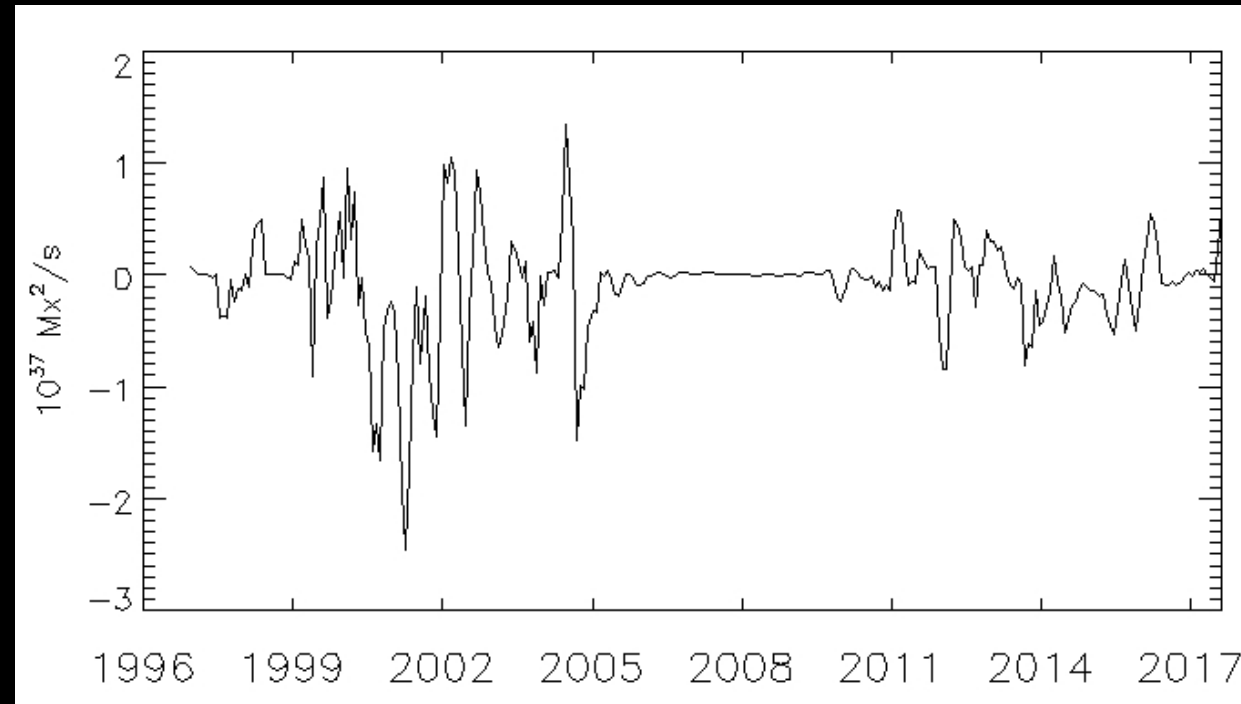


复现了观测上看到的太阳活动周净螺度的振荡特征

# 23-24太阳活动周的磁螺度传输率曲线

## Northern Hemisphere

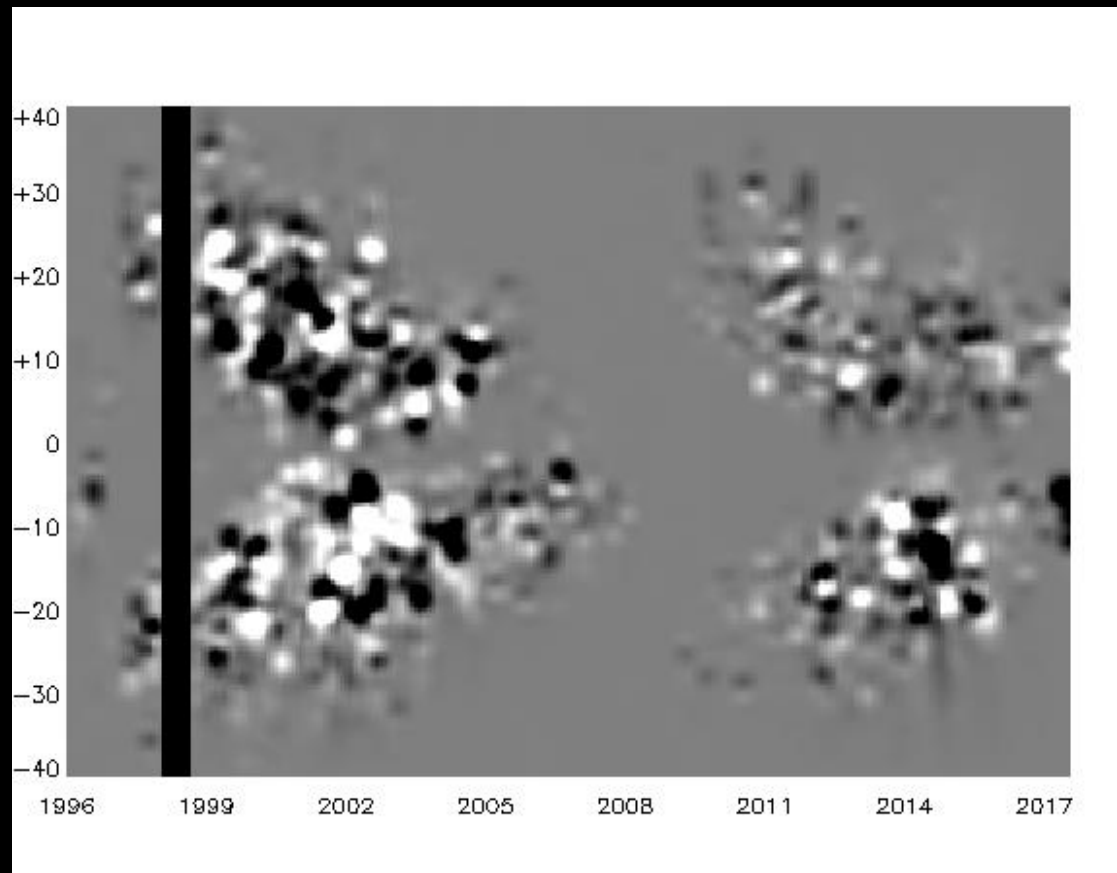
## Southern Hemisphere



**Mixture of positive and negative helicity flux with solar cycles**

# NEXT: 磁螺度传输的蝴蝶图和高精度的磁螺度数值模拟

磁螺度分布的蝴蝶图对太阳发电机模型提出新挑战



Yang et al. in preparation

发展高精度的磁螺度计算模型

## Magnetic Helicity estimations in models and observations of the solar magnetic field

*Gherardo Valori\**, INAF - Osservatorio astronomico di Roma (Italy)

*Etienne Pariat\*\**, LESIA - Observatoire de Paris Meudon (France)

Yang Guo, Nanjing University (China)

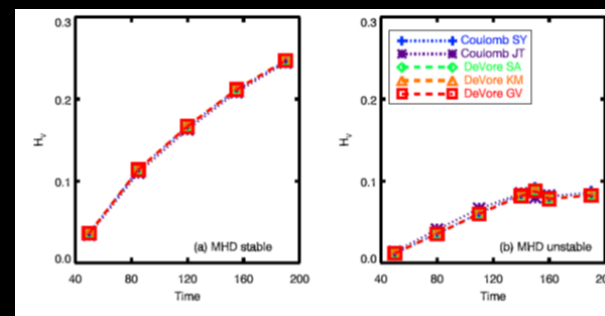
Yang Liu, Stanford University (USA)

Georgoulis Manolis, Academy of Athens (Greece)

George Rudenko, Institute of Solar-Terrestrial Physics SB RAS (Russia)

Shangbin Yang (National Astronomical Observatories, China)

Julia Thalmann, Institute of Physics/IGAM, University of Graz (Austria)



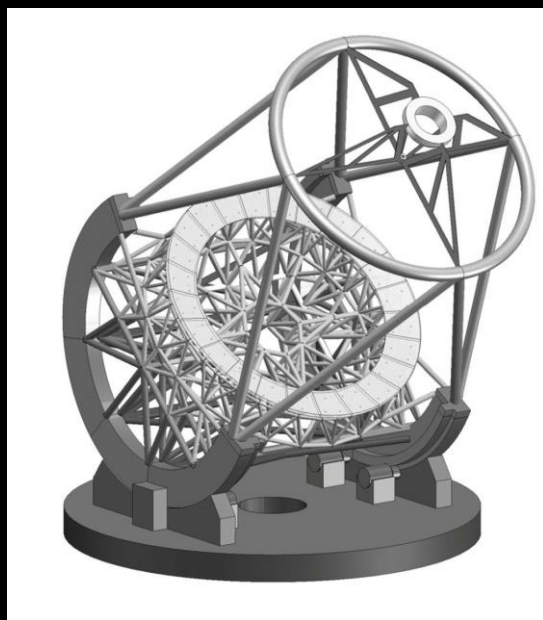
瑞士空间科学学院“国际磁螺度模型计算工作组”

# 面向未来的太阳矢量磁场观测

## 地基大口径

8m 口径CGST

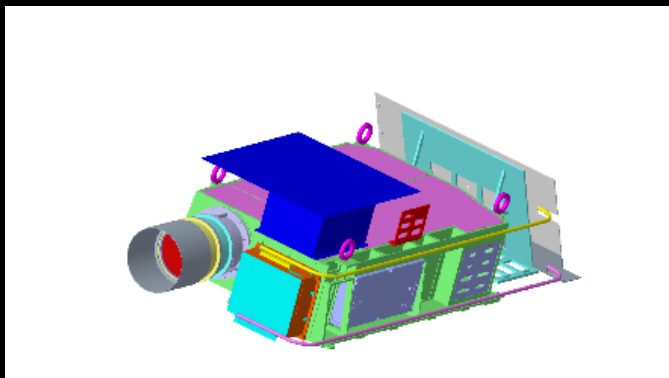
高分辨率的多波段偏振光谱测量



看得更清

## 空间望远镜

先进天基望远镜

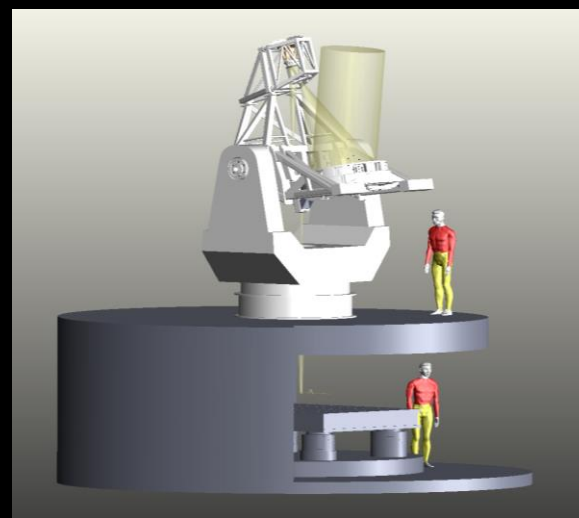


看得更稳

## 中红外望远镜

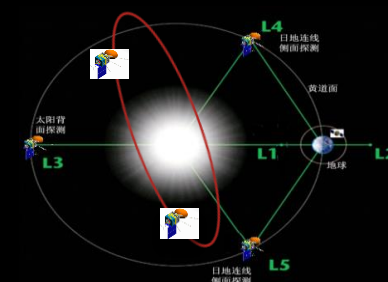
国家重大仪器专项AIMS

(青海冷湖天文观测基地)

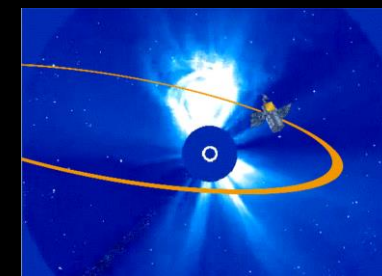


看得更准

## 立体探测



黄道面探测  
极轨探测



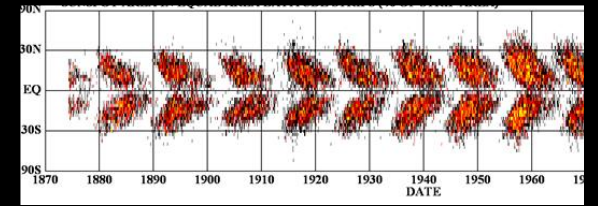
抵近探测

看得更全

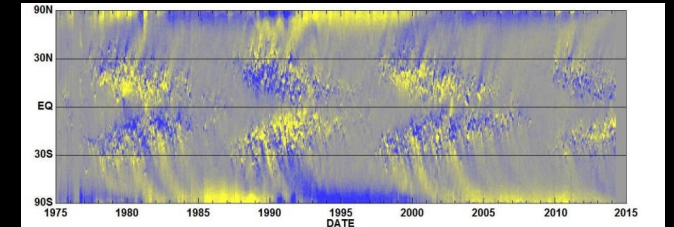
# SUMMARY

1. 高磁雷诺数是太阳发电机存在的前提条件, 也带来磁螺度守恒特性的约束;
2. 从平均场发电机出发, 引入螺度守恒条件, 复现了观测上发现的活动周磁螺度演化特征, 和太阳黑子活动的长周期强度变化 (Wolf数) 和非对称性的现象;
3. 太阳发电机问题的观测约束正从黑子的蝴蝶图逐步过渡到磁螺度传输的蝴蝶图, 在我们目前的模型中使用的是边界条件和螺度扰动模型还比较简单, 推进Helicity-Driven Solar Dynamo;
4. 引领未来的空间和地基的太阳磁场测量。

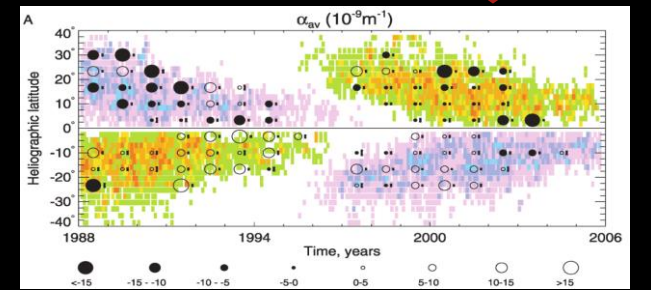
太阳黑子的蝴蝶图



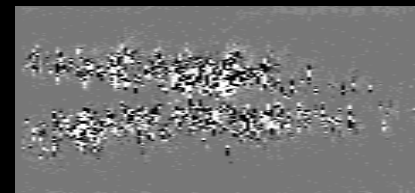
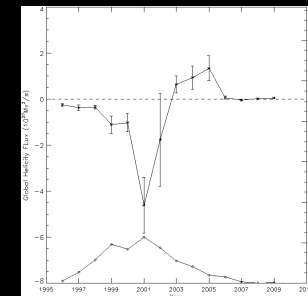
视向磁场的蝴蝶图



矢量磁场的蝴蝶图



磁螺度传输的蝴蝶图





谢谢 ！