宇宙线太阳阴影的研究

—-从ARGO-YBJ到LHAASO

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西南交通大学

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主要内容

- 背景

- ARGO-YBJ日影的研究

- 小结

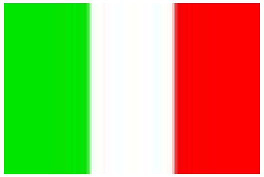
ARGO-YBJ is an Extensive Air Shower detector optimized to work with showers induced by primaries cosmic rays of energy

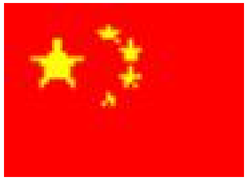
E > a few hundreds GeV

This low energy threshold is achieved by:

- operating at very high altitude (4300 m)
- using a “full coverage” detection surface

ARGO-YBJ collaboration





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INFN and Università “Federico II” di Napoli
INFN Catania, Univ. and INAF/IASF di Palermo
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INFN and INAF/IFSI di Torino

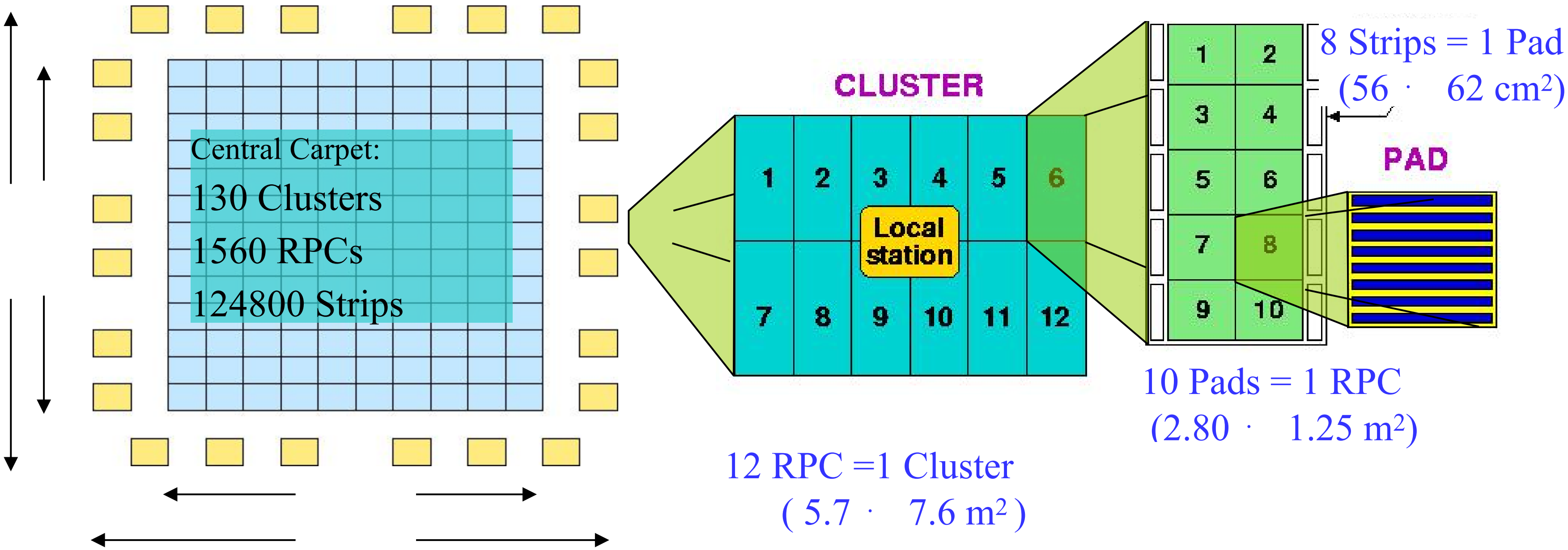
IHEP, Beijing
Shandong University,Jinan
South West Jaotong Univ., Chengdu
Tibet University, Lhasa
Yunnan University, Kunming
Zhengzhou University
Hongkong University
Hebei Normal University

Spokesmen

Prof. B. D’Ettorre Piazzoli

Prof. Cao Zhen

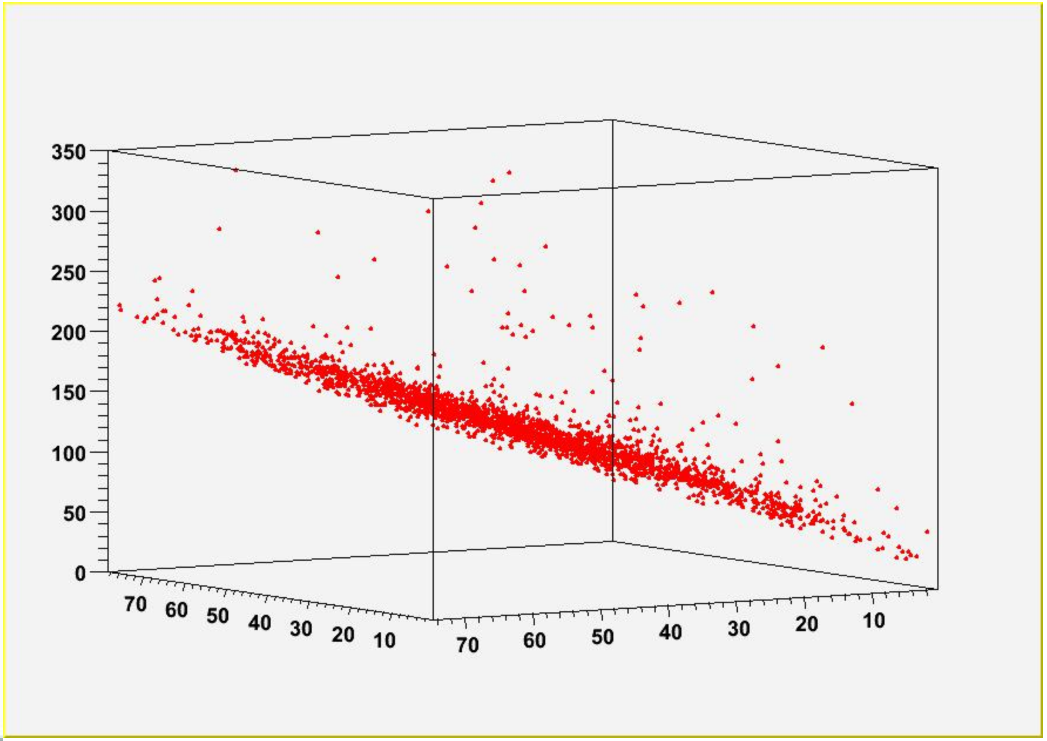

ARGO 实验厅



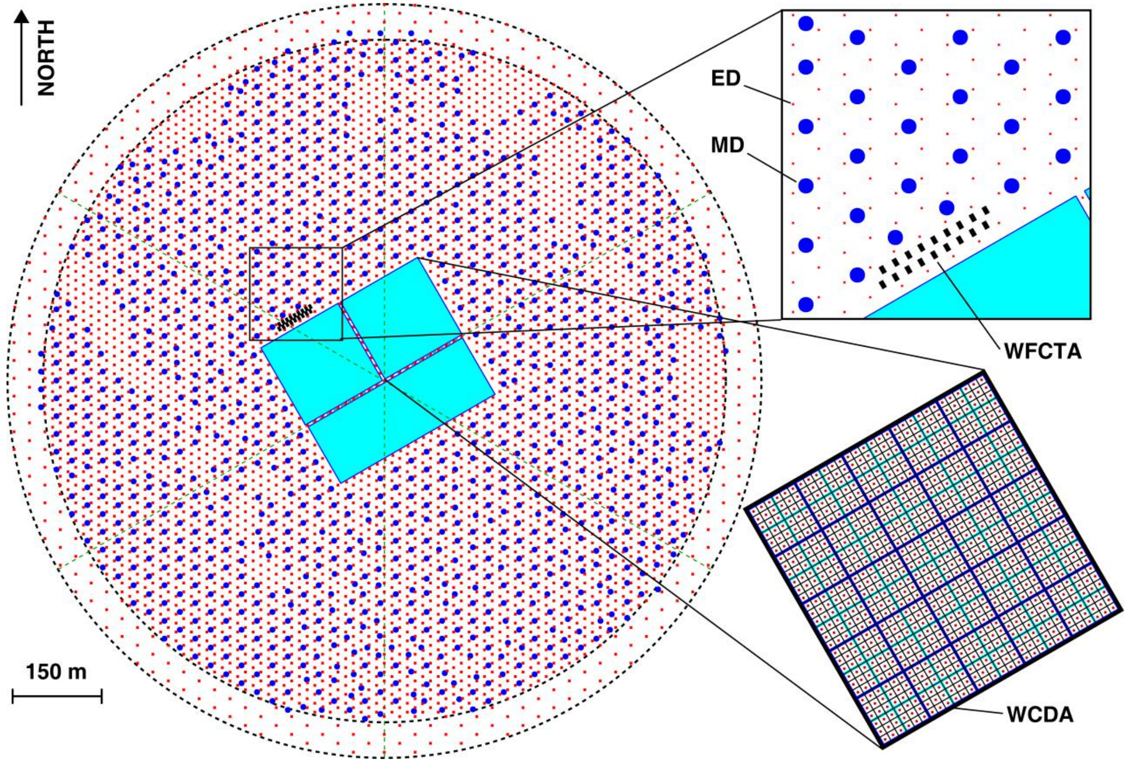
Layer of RPC covering
~ 5600 m^2

Space pixel: *7×62 cm^2 (1 strip)*
Time resolution: *≈ 2 ns*

A real Shower(Event)



LHAASO: Large High Altitude Air Shower Observatory @4400m



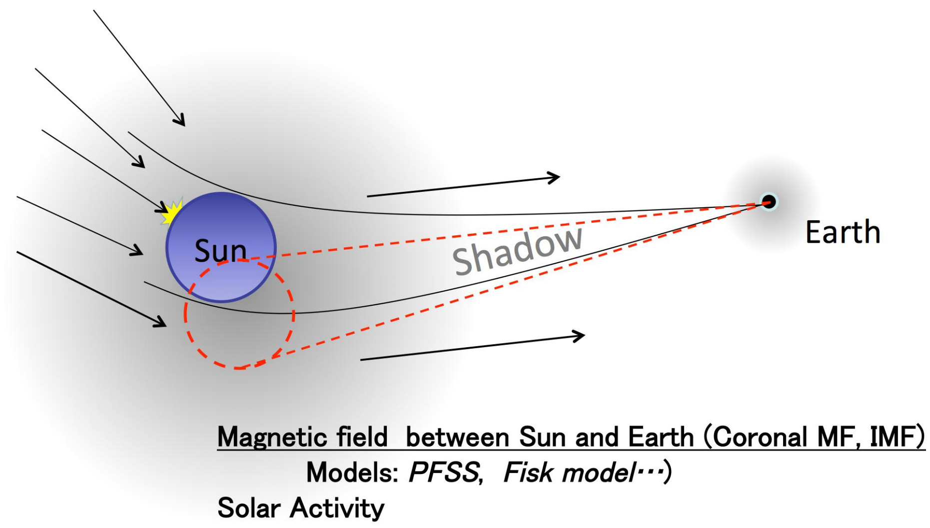
LHAASO

（5195 ED,1171 MD, 78000m^2 WCDA)

- 开展全天区扫描，寻找新的伽马射线源
- 对河内源及临近源高端能谱的测量
- 宇宙线能谱及成分的精确测量
- 太阳物理方面的研究
- 空间科学及天气预报

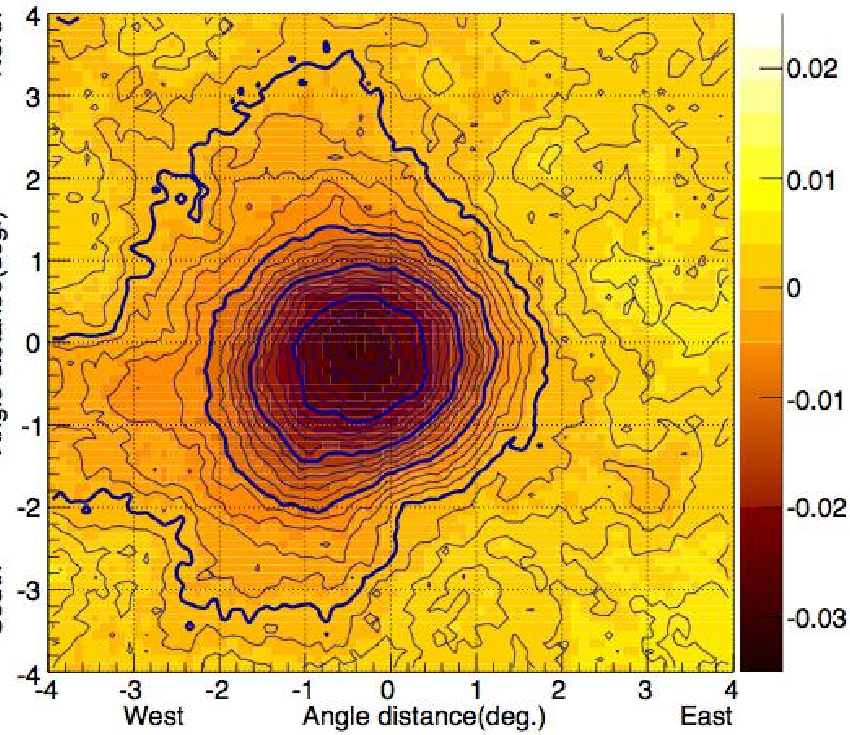
Sun shadow with Cosmic Rays

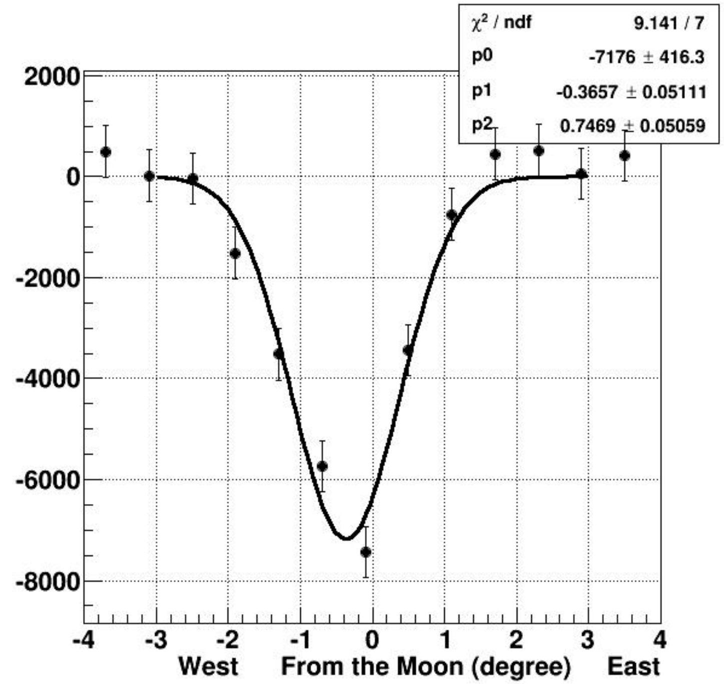
Sun block the cosmic rays

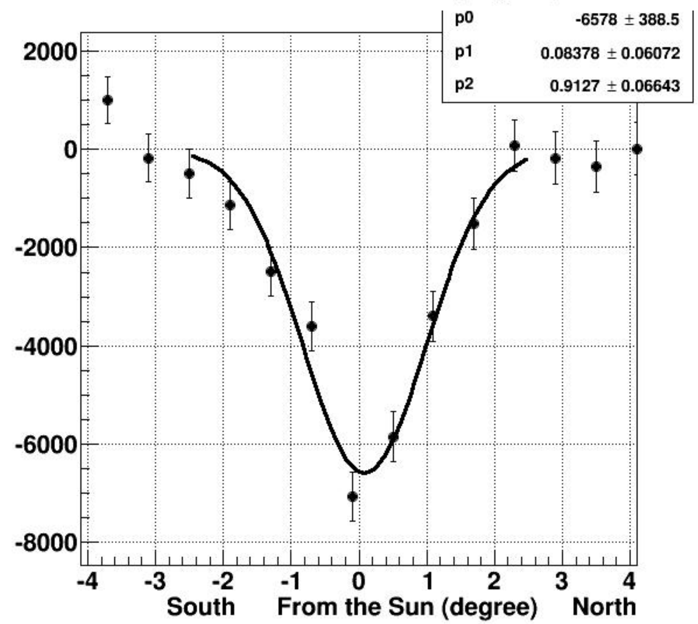


- 1957, Concept by Clark
- 1991, first Sun+Moon shadow(4.9sigma) by CYGNUS
- Only several σ sun shadows with CASA, Milagro, SOUDAN2, MACRO, L3+c
- Further physics with AS γ , ARGO-YBJ， LHAASO

Sun shadow by ARGO-YBJ







根据Li－Ma公式计算统计显著性缺失

拟合日影中心在东西、

南北方向的位置

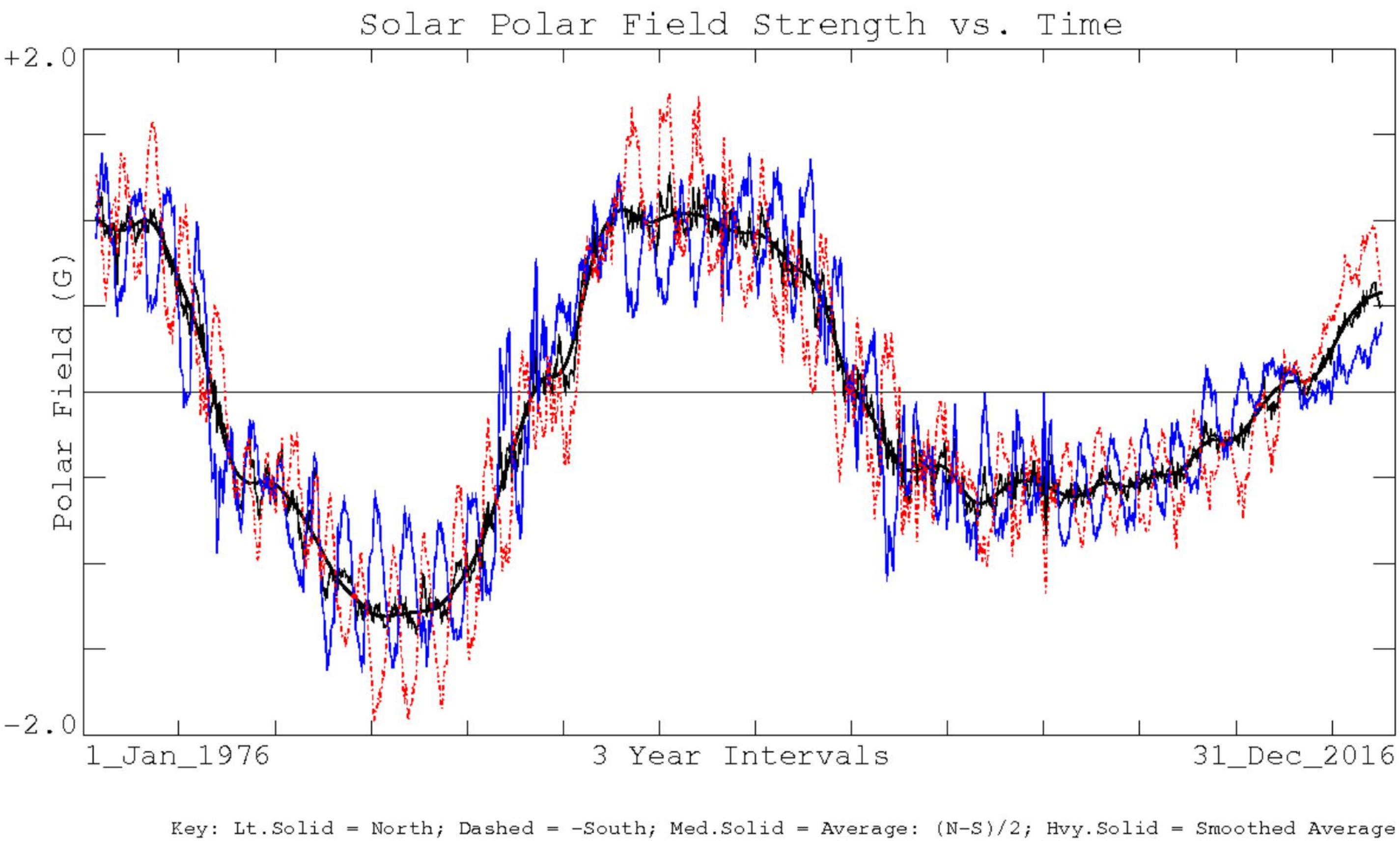
日影在东西方向上的偏移

一太阳发电机模型研究

太阳活动相对平静时， 日影在东西方向上的偏移主要由地球磁场和太阳极区磁场决定

太阳极区磁场的周期性

From Wilcox Solar Observatory

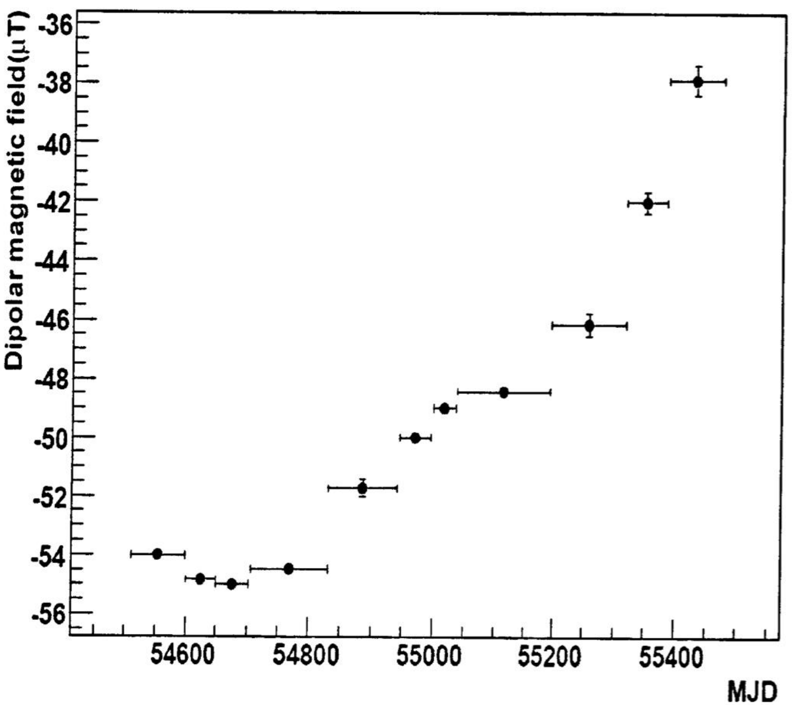


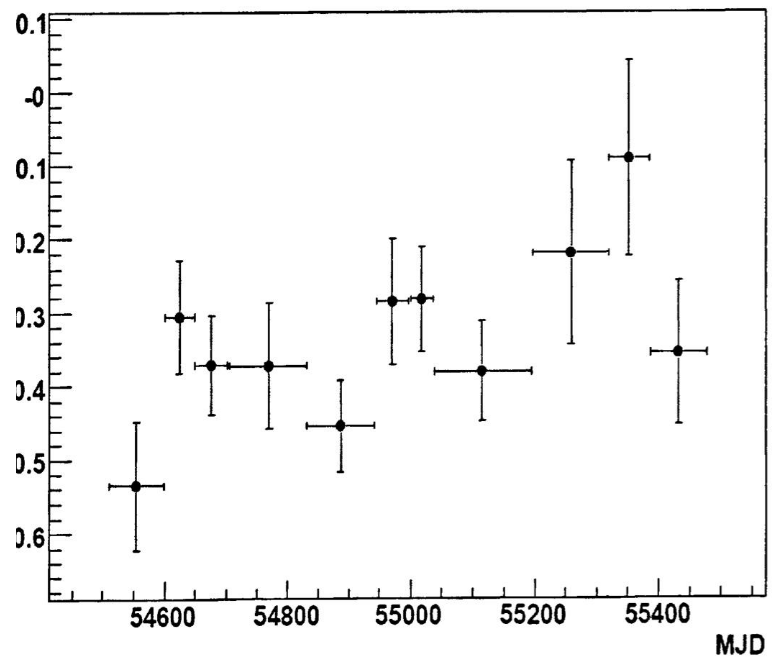
太阳发电机理论主要用来解释太阳活动的11年的周期性，是太阳物理最核心的问题

太阳极区磁场是发电机理论的关键参量之一

日影在东西方向上的偏移

叶妮，2012， 硕士论文，太阳磁场变化和宇宙线日影的关联





太阳极区磁场与日影在东西方向上的偏移的相关性仍不能由ARGO确定

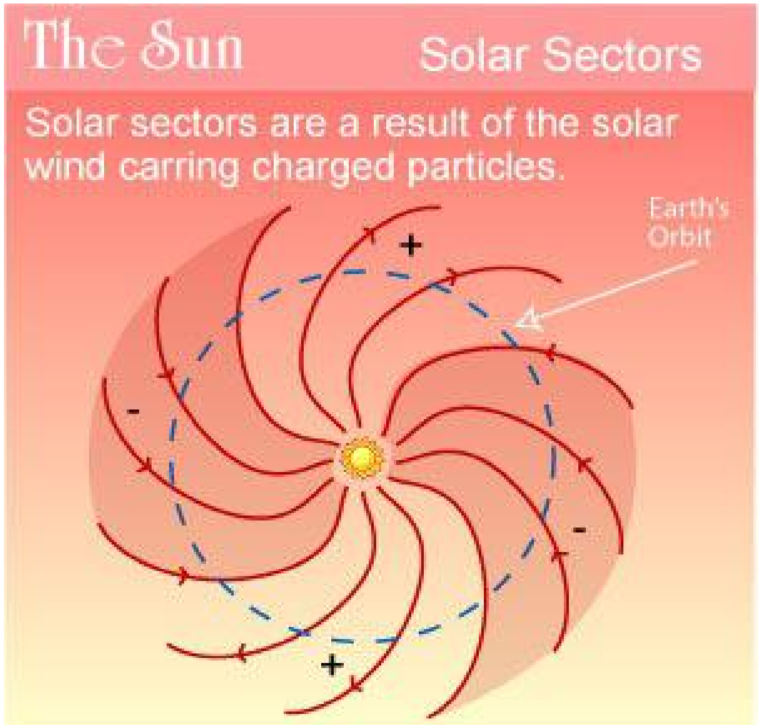
太阳活动极大时太阳极区磁场的翻转（2025年左右 Lhaaso 5 years old?）

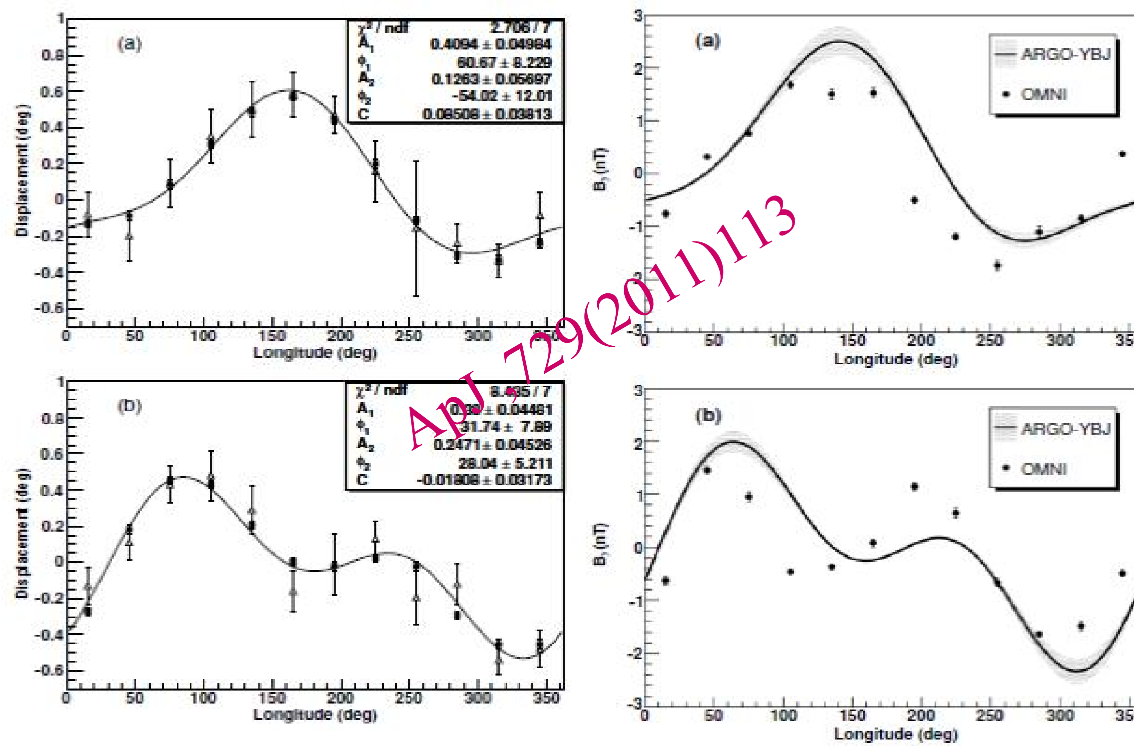
日影在南北方向上的偏移

太阳活动相对平静时期，宇宙线日影在南北方向上的偏移主要由行星际磁场决定

行星际磁场的测量和空间天气预报

with the displacements of the sun shadows in 2-sector and 4-sector pattern of IMF





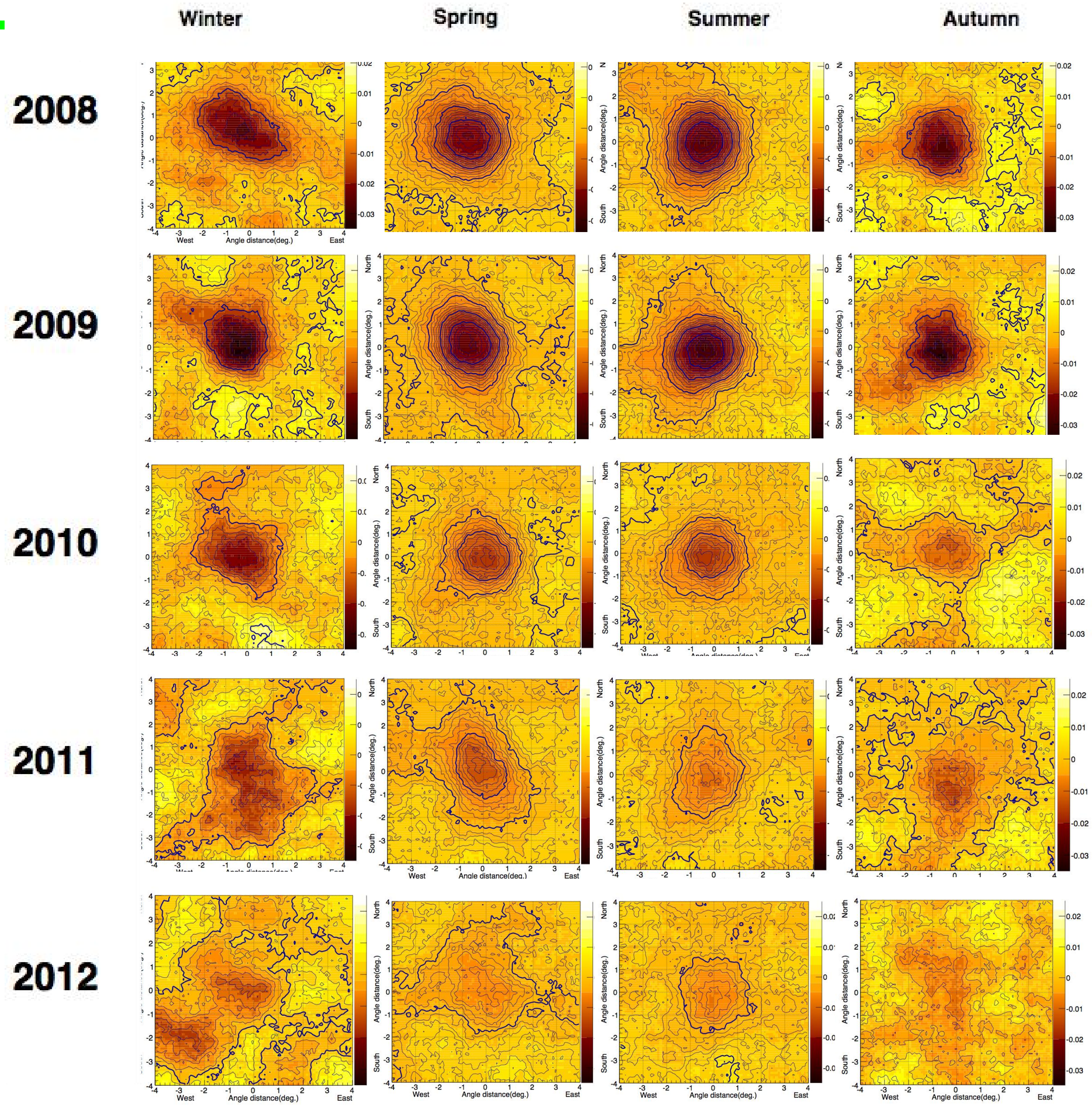
目前的空间天气预报主要由Goes卫星测量到达地球附近的粒子流强，时间延迟4～7天

Lhaaso的高灵敏度实现更快的空间天气预报？

日影缺失的变化

—行星际磁场变化的物理机制
—行星际磁场模型
—太阳磁场模型
—日球磁场模型

Variation of Sun shadow in nearly half solar cycle



- Contours represents defic
  statistics significance(DSS
- The absolute of DSS for
  the innermost thicker conto
  lower 5sigma than the most
  in the map,
  and it's neighbor thicker
  contours similar as well
- Colors mean fraction of the
  deficit in each grid 0.1 times 0.

•Sudden variation in early 2010

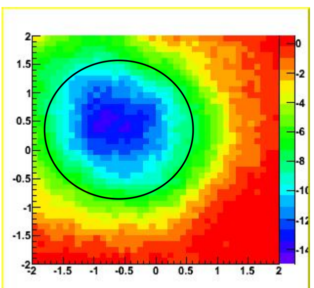
F.R. Zhu et al, ICRC2015

Deficit ratio in 16 intervals in 2007.11——2013.02 from Moon and Sun

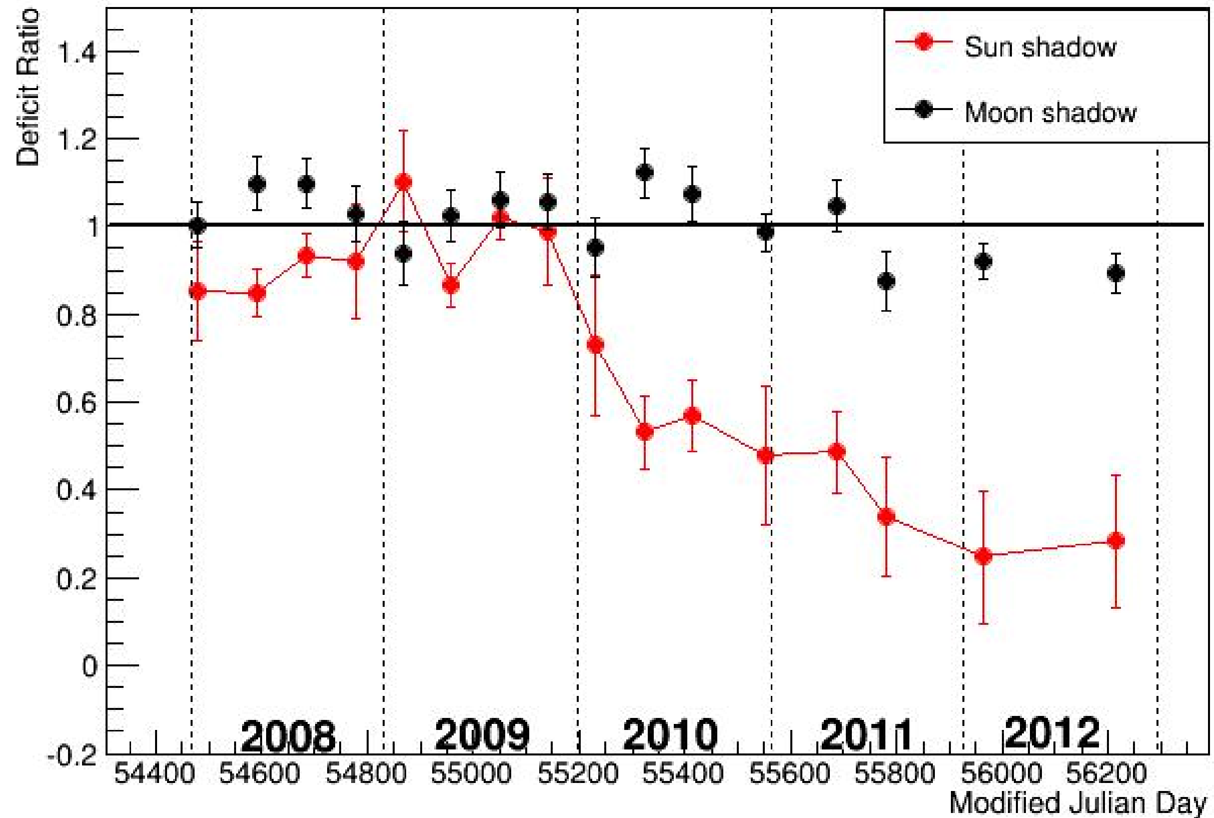
Deficit ratio of the sun shadow or moon shadow:

F.R. Zhu et al, ICRC2015

- The ratio of the deficit count compared to the expected one
- A non-dimensional valuable
- Independent of the exposure

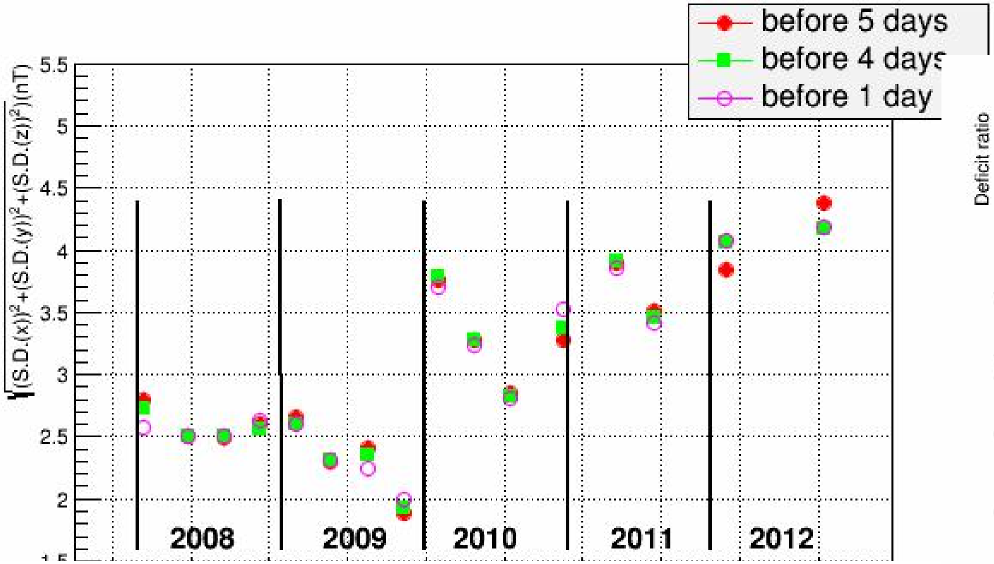


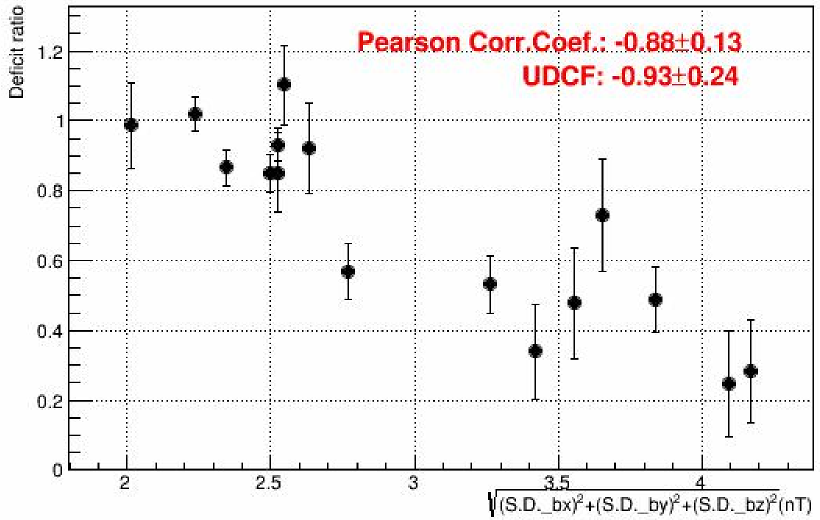
$$N_{def} = [1 - e^{-0.5\cdot(\frac{R}{\sigma})^2}] \cdot N_{sun}$$

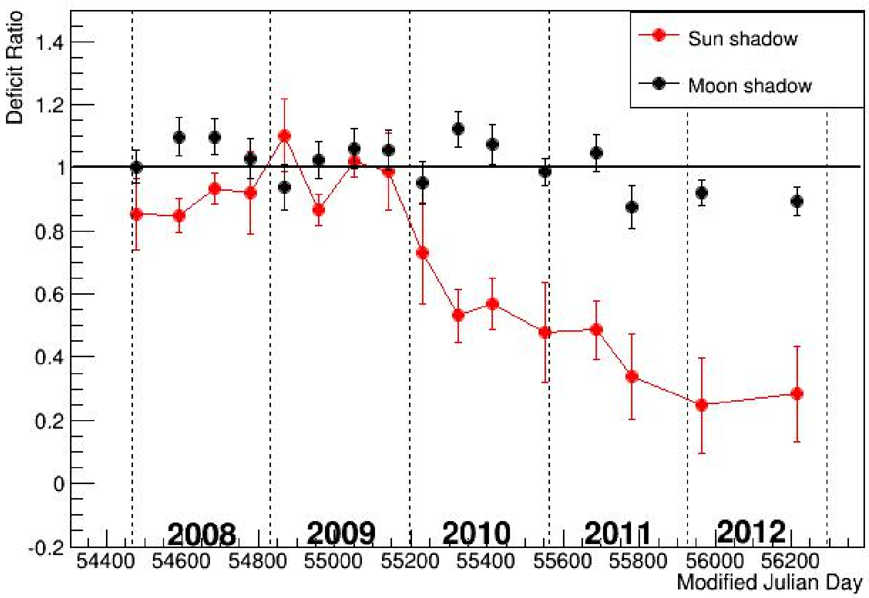


- *Deficit ratio of the Moon shadows in 16 intervals are stable*
- *Deficit ratio of the Sun shadows in 16 intervals is function of time,decrease in 2010*
- Possible physical mechanism:1. 太阳磁场的结构和强度 2. 行星际磁场的变化

Deficit ratio Vs. S.D. of the IMF



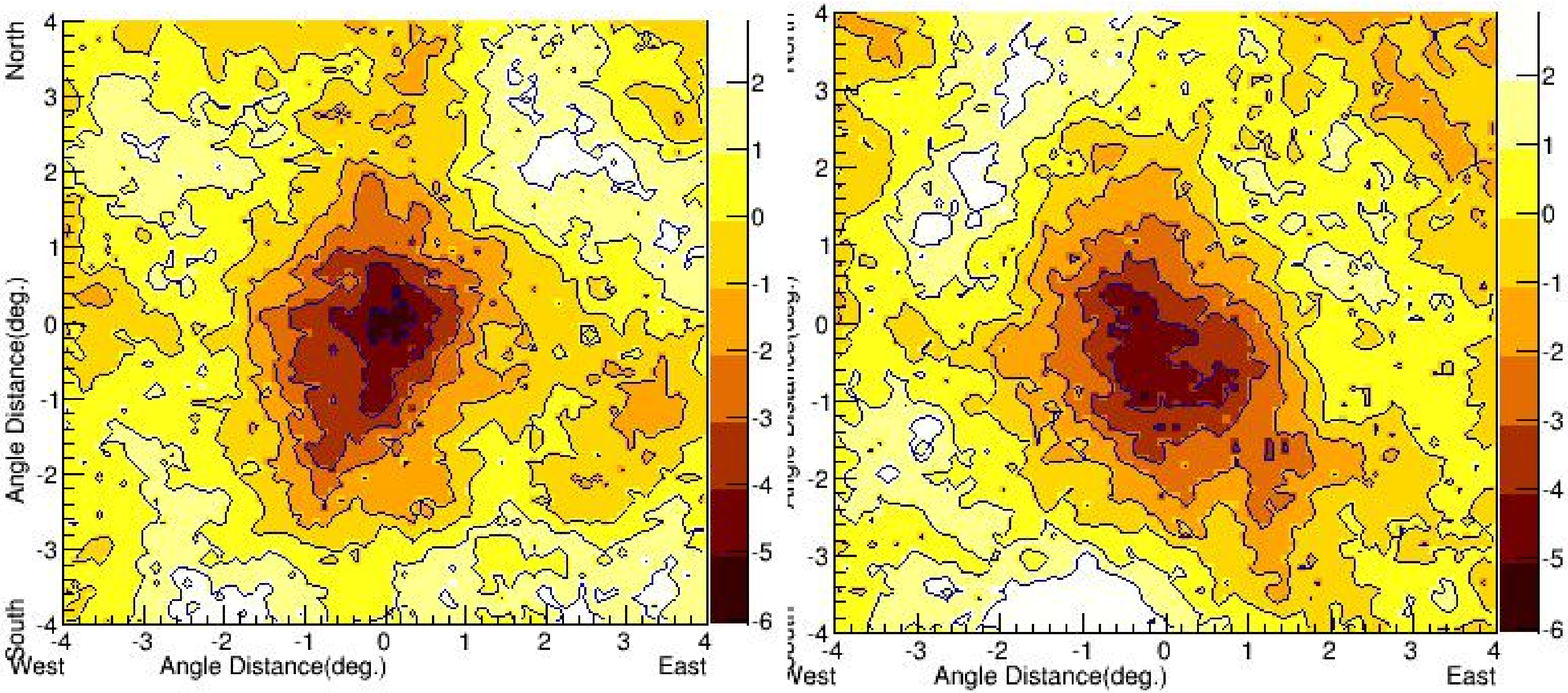




- deficit ratio have better synchronous variation with S.D. of the vector IMF than its components of Bx,By,Bz and Bx+By,Bx+Bz, By+Bz

- deficit ratio have better synchronous variation with S.D. of the vector IMF than sunspot

halo CME前后日影的观测比较



LHAASO积累更多的数据，确定日影的行星际磁场的变化机制

大尺度太阳磁场模型(PFSS)

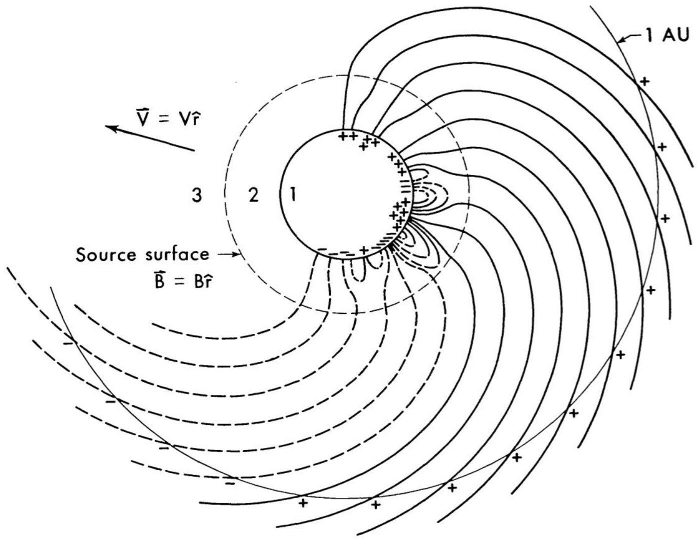


Fig. 1. Schematic representation of the source surface model. The photospheric magnetic field is measured in region 1 at Mount Wilson Observatory. Closed field lines (loops) exist in region 2. The field in this region is calculated from potential theory. Currents flowing near the source surface eliminate the transverse components of the magnetic field, and the solar wind extends the source surface magnetic field into interplanetary space. The magnetic field is then observed by spacecraft near 1 AU.

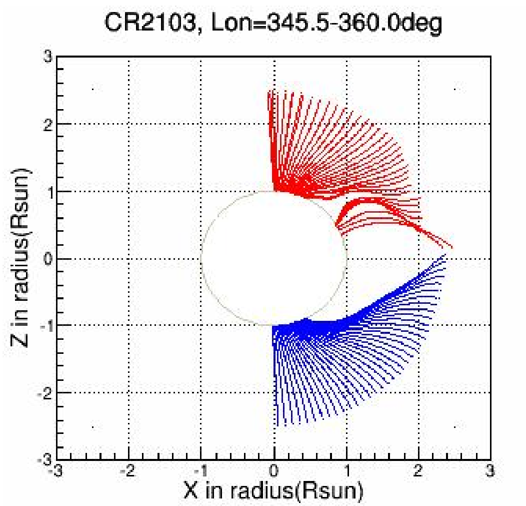
1. 该模型假定太阳大气中没有日冕电流，电势是等势体

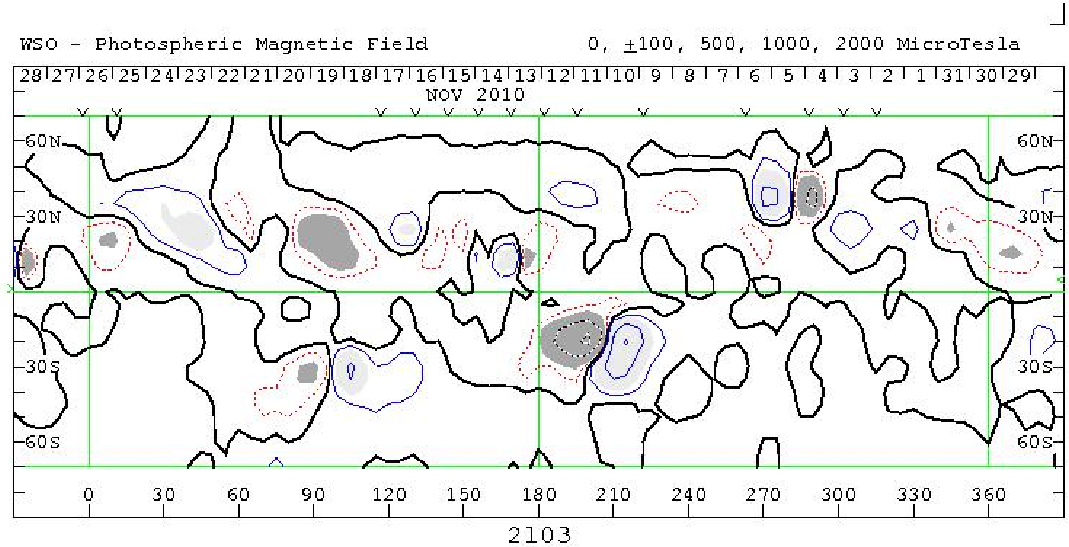
2. J. Todd Hoeksema对该模型进一步完善和发展，完成博士论文Structure and Evolution of the Large Scale Solar and Heliospheric Magnetic Field

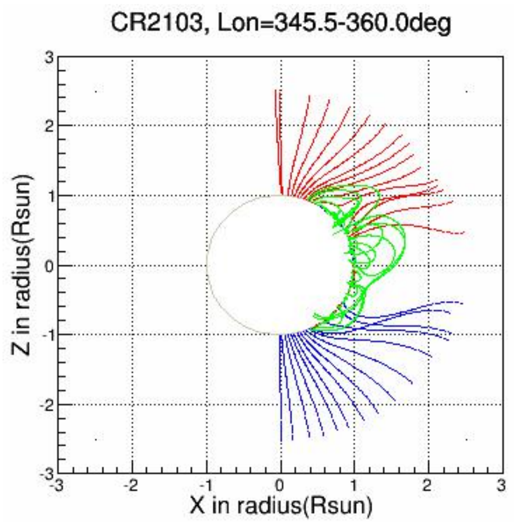
3. 目前该模型广泛引用在Solar Dynamics Observatory搭载的望远镜对日球层磁场的研究中

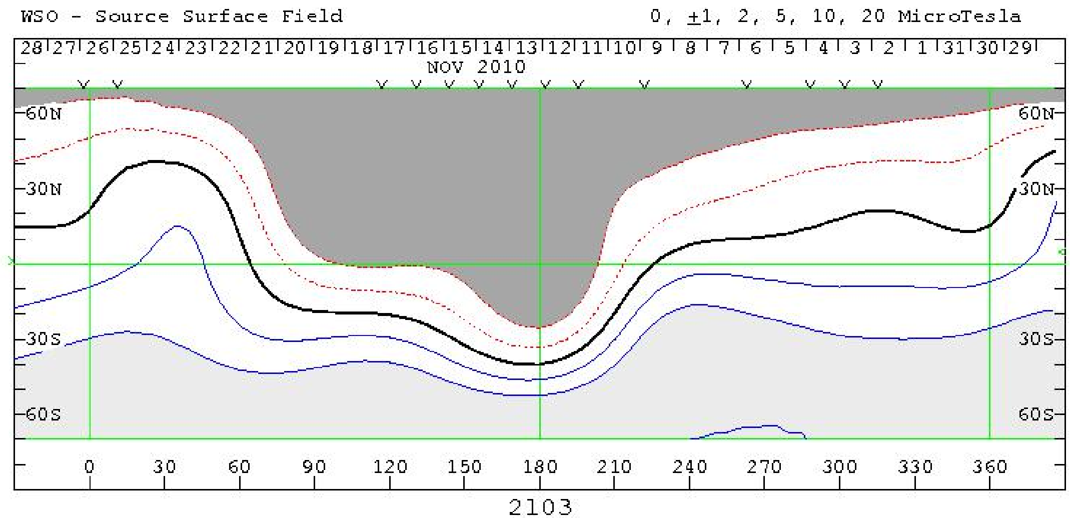
4. PFSS理论的学习和数值的计算，利用IDL软件进行动画制作

PFSS 的数值计算（2.5太阳半径内

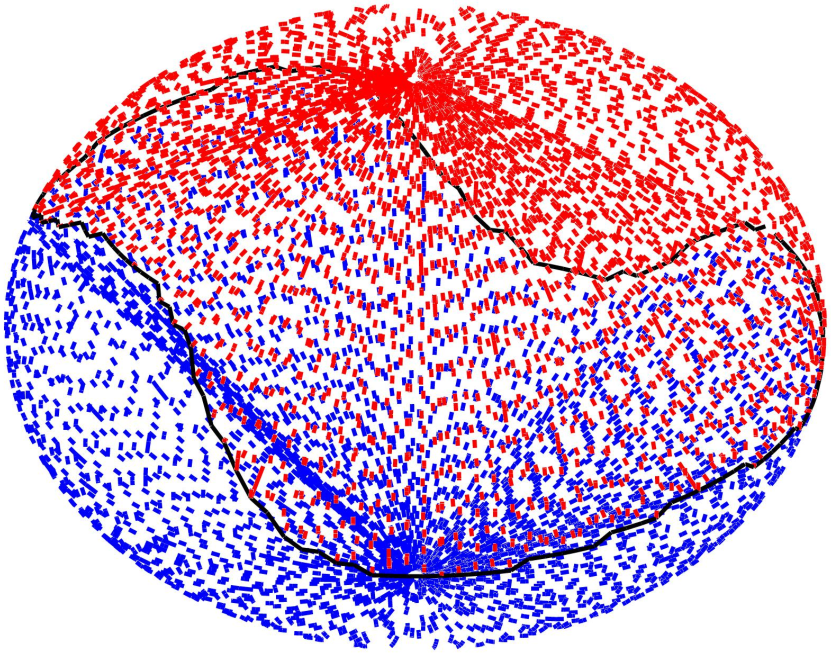








magnetic field neutral line for CR2103



大尺度太阳磁场模型(HCCS)

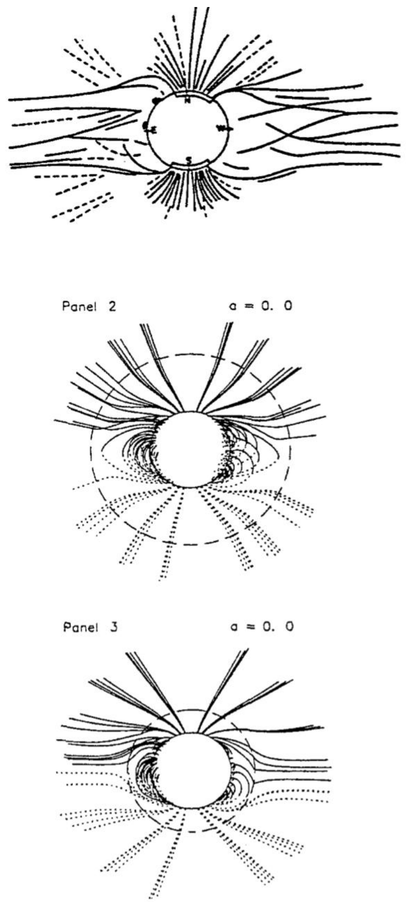


Fig. 1. Comparison of the original drawing of the solar total eclipse observed on 23 October, 1976 (*top*) (Loucif and Craag, 1988) with the magnetic field structures predicted using the source-surface model (*middle*), and the current-sheet model (*bottom*). The near-limb field lines in the model should outline density structures observed during the eclipse.

HCCS模型：Horizontal Current Source Surface

1. 基于静态磁流体力学中的平衡和源表面技巧
2. 内边界是太阳光球，外可到15太阳半径
3. 预测大尺度磁场模型方面和PFSS模型类似
4. 能够预期日冕中等离子体的性质
5. HCCS理论的学习和数值的计算研究

Solar Physics 151:91-105,1994
by XUEPU ZHAO AND J. TODD HOEKSEMA

下一步：

HCCS模型的数值结构

放进ARGO模拟中去进行研究

LHAASO的日影研究模拟

小结

- ARGO能定量测量宇宙线日影
- 开展部分相关物理研究
- 预期LHAASO取得更好得物理结果，期望在太阳发电机研究、日球磁场的演化及大尺度结构、空间科学方面有所突破，并取得一定的应用价值。