



The cosmic-ray shadow of the Sun observed with the Tibet air shower array, as a probe of the solar magnetic field

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Outline

- Tibet ASγ Experiment
- Sun shadow observation to probe solar MFs
- Application to space weather
- Summary





Basic idea: T. K. Sako et al., Astropart. Phys. 32, 177 (2009)

Measurement of # of μ in AS $\rightarrow \gamma / CR$ discrimination Started operation in 2014



Sun Shadow



→ Sun shadow provides unique method to probe solar MFs experimentally.





MC Simulation of Sun Shadow

- Anti-particles are shot back to the Sun from the Earth assuming CR spectra, compositions, detector responses
- Particle trajectories are traced assuming the solar MFs between the Sun and the Earth
- -> Events hitting the Sun make the Sun shadow



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Time Dependent Coronal MF

<u>Corona</u> -> potential field models (*PFSS and CSSS*) Extrapolated from the photospheric MFs measured by Kitt Peak (KPVT/SOLIS) in each Carrington rotation (~27 days) <u>IMF</u> -> Parker spiral model with latitude dependence of the solar wind velocity taken into account.
<u>Geomag.</u>-> Dipole model

AS v



Evaluation of Solar MF models

AS v

M. Amenomori et al, PRL, 111, 011101(2013)



First demonstration to evaluate the coronal MF models

→ A clear solar-cycle variation of the deficits CRs are scattered by solar magnetic field.



Fibet

AS v

Detector stability calibration ¹²





Deficit – Obs/MC <u>Exclude ECMEs</u> - 3 TeV

AS v





Indirect Measurement of IMF



Sector structures (Toward/Away) in the IMF \rightarrow Spiral structure makes B_x and B_y $\rightarrow B_y$ shifts the Sun shadow to South / North at Toward / Away sector



Indirect Measurement of IMF

M. Amenomori et al., PRL 120, 031101 (2018)



Amount of the shift is proportional to total B_y b/w Sun and Earth → Indirect measurement of IMF



Indirect Measurement of IMF

M. Amenomori et al., PRL 120, 031101 (2018)





Forecast of CME-> Space Weather Forecast





Summary

The Sun shadow is sensitive to:

- Solar magnetic field (including coronal magnetic field)
- IMF
- (Earth-oriented) CME at 3TeV.

→ Application to space weather forecast: with sufficient statistics, the Sun shadow can be observed during 1-day observation vs. CME arrival time 4 days.

Detailed simulation of the Sun shadow by MHD is under way.