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Interplanetary Propagation of Coronal Mass Ejections ~Statistical and Case Studies by IPS~

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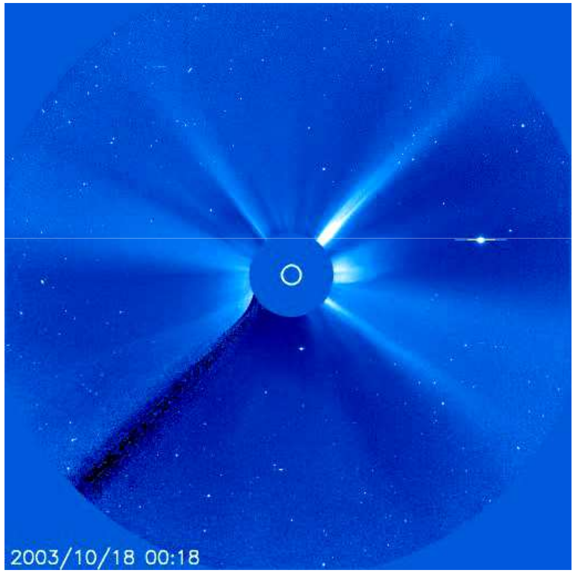
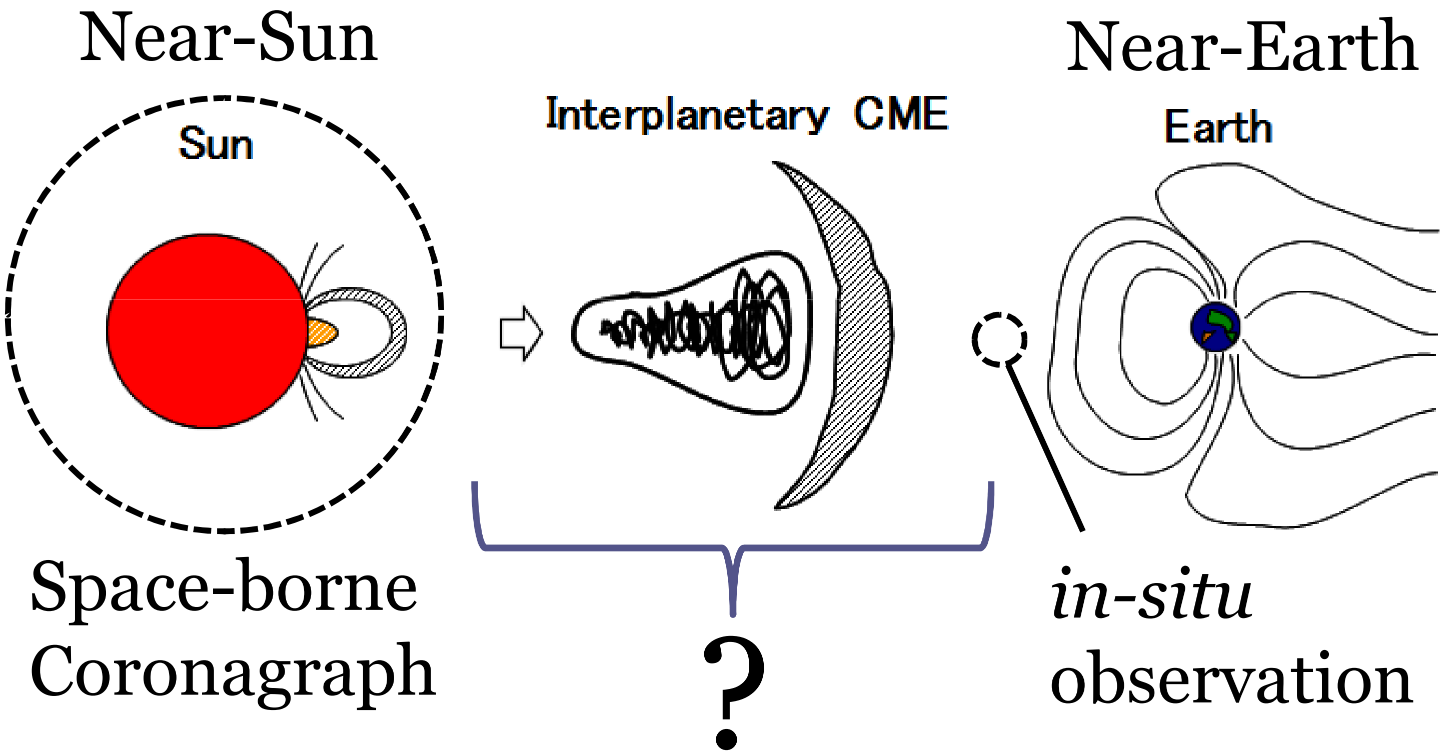
Introduction

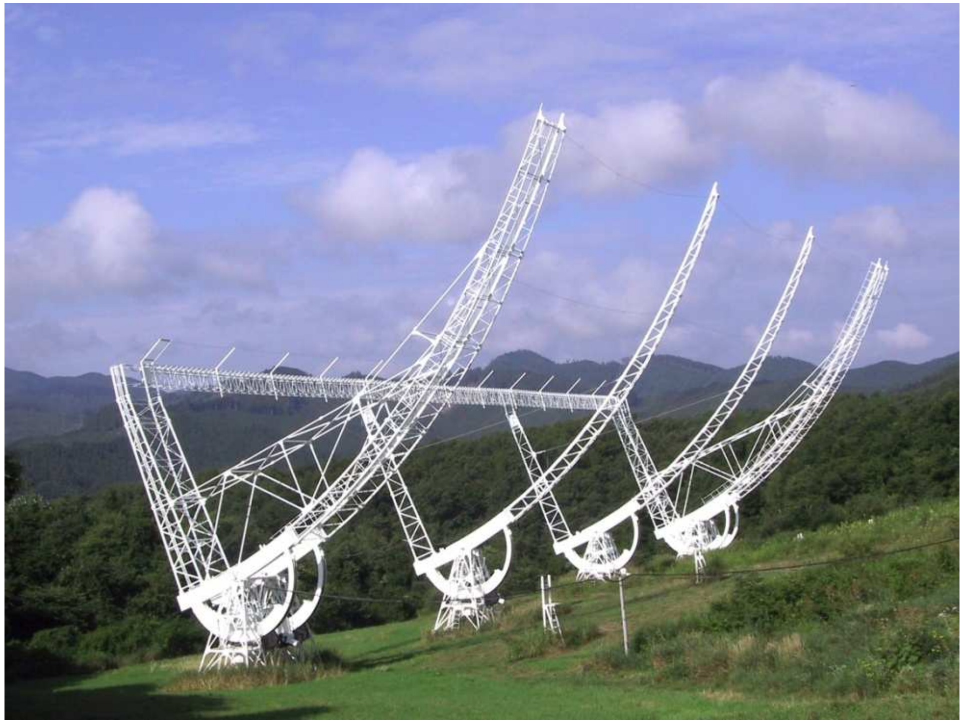


SOHO/LASCO C3
(ESA&NASA)



- A large amount of plasma is expelled from the Sun into the interplanetary space = Coronal mass ejection (CME).
- Understanding the propagation of CMEs is very important for the space weather forecast.
- Need more CME observations between 0.2 and 1 AU.

Our Radio Telescopes for IPS Observations

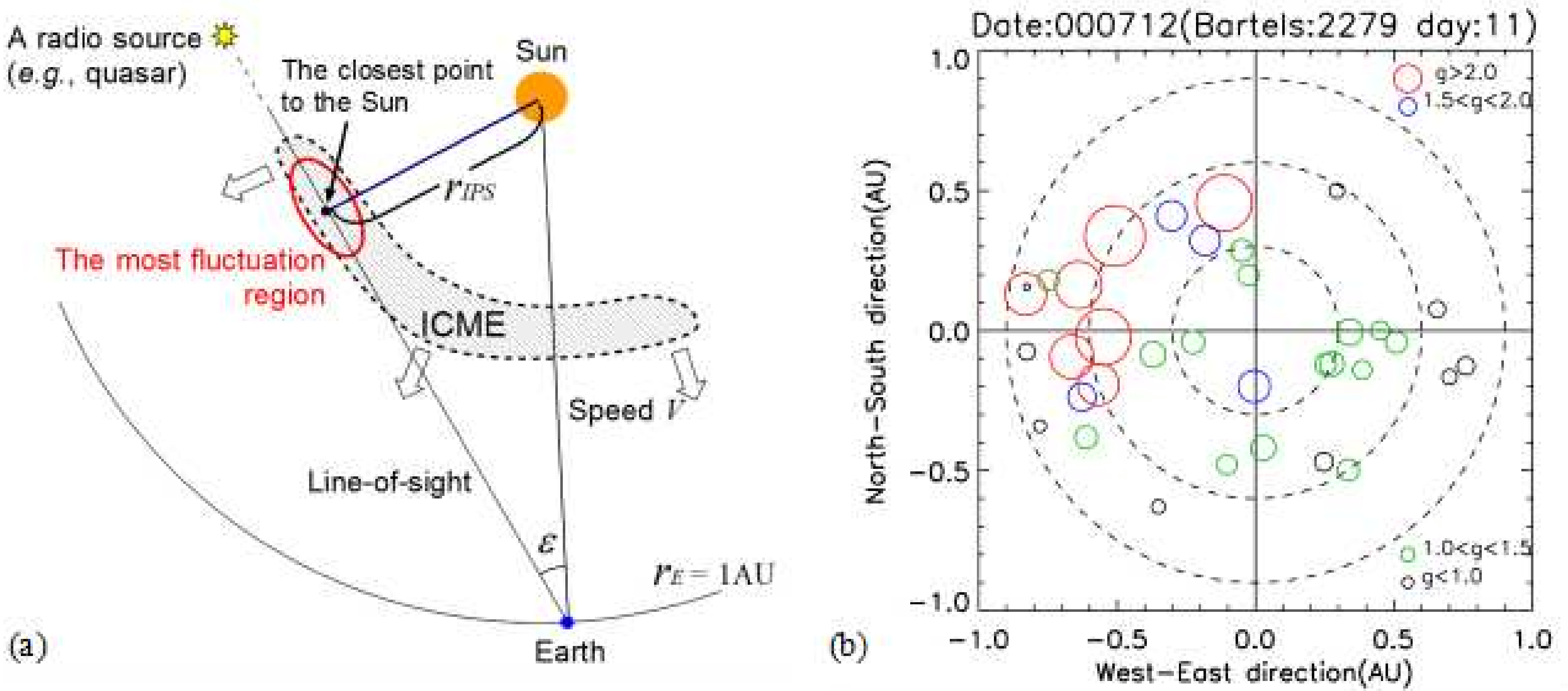


↑ Kiso IPS Telescope [frequency: 327±5MHz, aperture: ≈ 2000 m^2]

↑Solar Wind Imaging Facility (SWIFT) [same frequency, aperture: ≈ 4000m^2]

- The *g*-value is obtained using Kiso IPS Telescope (1997 — 2009) and SWIFT (2010~).

CMEs in the Interplanetary Space

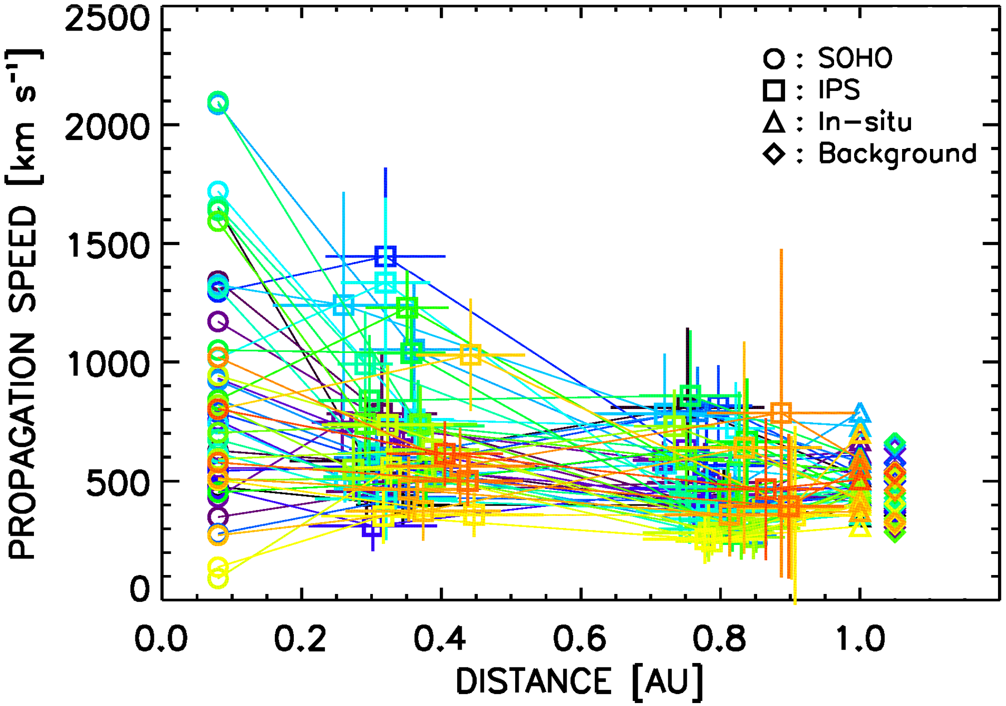


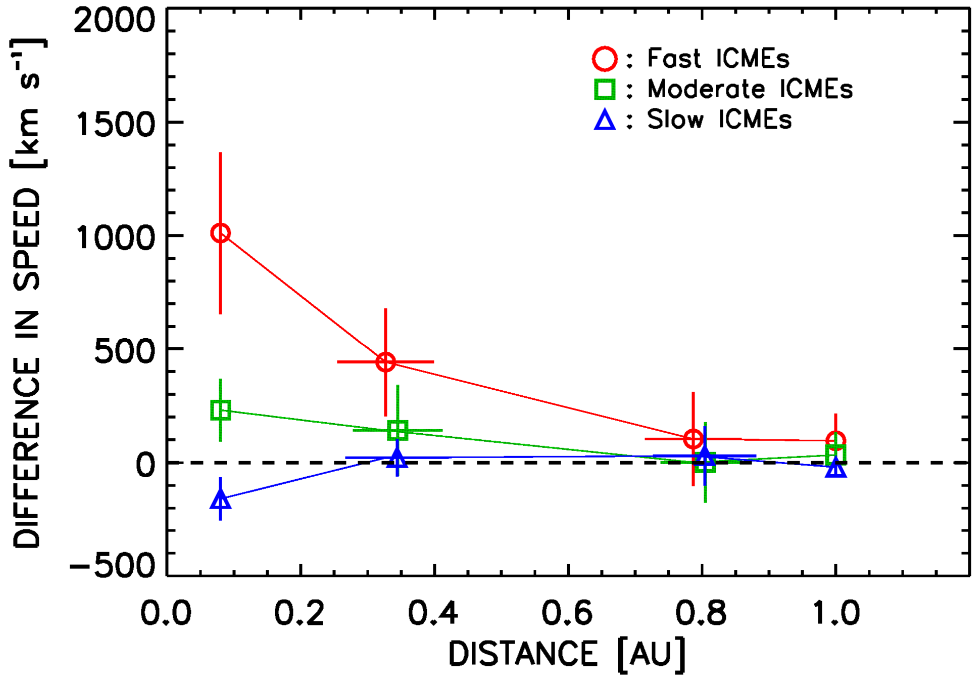
- A sky-map of enhanced *g*-values (b) provides information on the spatial distribution of CMEs between 0.2 and 1 AU.
- Using SOHO/LASCO, IPS, and *in-situ* observations, CMEs are identified in the near-Sun region, interplanetary space, and near-Earth region, respectively.

I. Statistical Study

General Properties of CME propagation

Speed Profiles for 46 CMEs identified by SOHO/LASCO, IPS, and *In-situ* Observations During 1997 — 2011





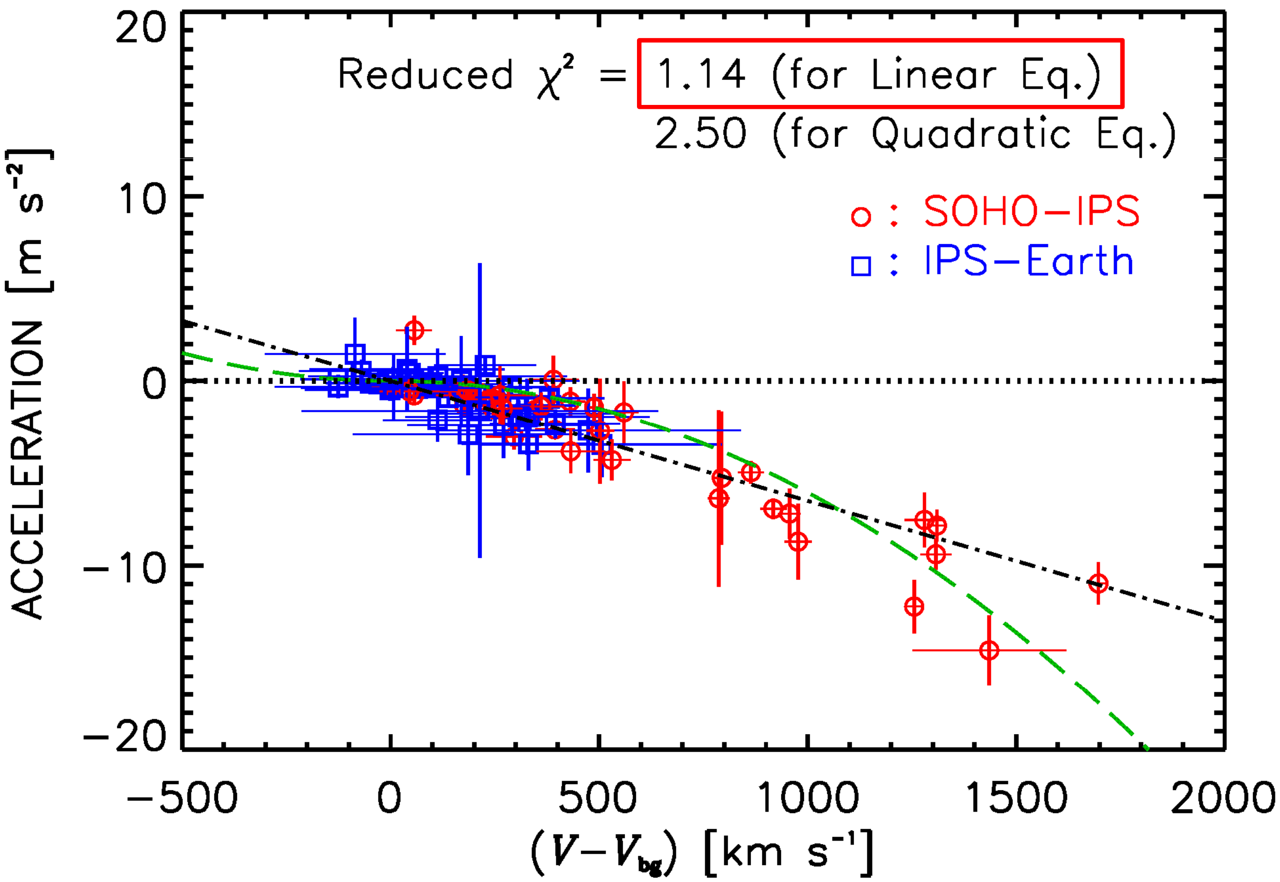
Fast CMEs $[(V - V_{bg}) > 500 \text{ km s}^{-1}]$ **: 15**

Moderate CMEs $[0 \text{ km s}^{-1} \leqq (V - V_{bg}) \leqq 500 \text{ km s}^{-1}]$ **: 25**

Slow CMEs $[(V - V_{bg}) < 0 \text{ km s}^{-1}]$ **: 6**

Kinematics of Fast and Moderate CMEs

- A linear equation (dash-dotted line) is more appropriate than a quadratic one (broken line) to describe the motion of fast and moderate CMEs.

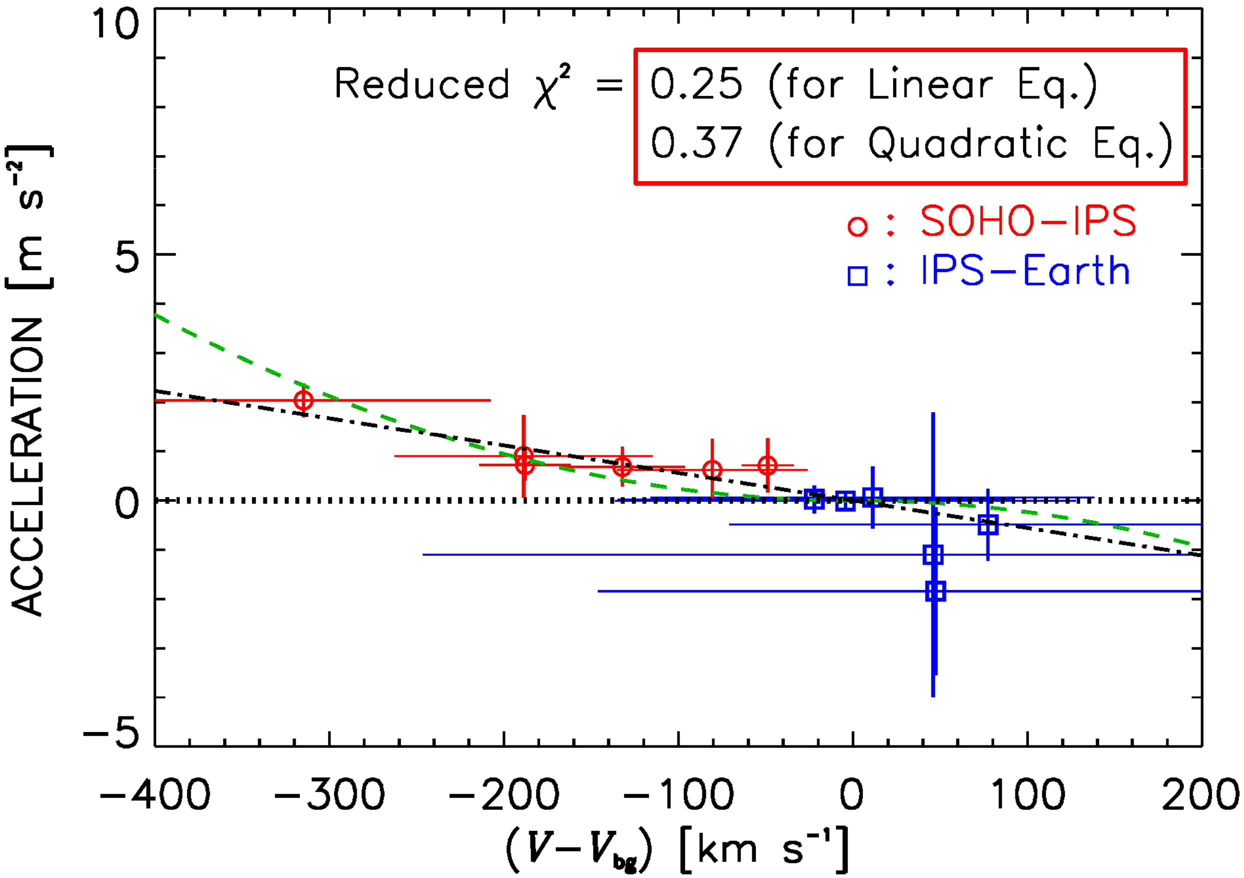


$$a = -\gamma_1 (V - V_{bg})$$
$$\gamma_1 = 6.51(\pm 0.23)\times 10^{-6} s^{-1}$$

$$a = -\gamma_2 (V - V_{bg})|V - V_{bg}|$$
$$\gamma_2 = 6.06(\pm 0.23)\times 10^{-12} m^{-1}$$

Kinematics of Slow CMEs

- There is no significant difference between a linear equation (dash-dotted line) and a quadratic one (broken line) for describing the motion of slow CMEs.



$$a = -\gamma_1 (V - V_{bg})$$
$$\gamma_1 = 5.58(\pm 1.77)\times 10^{-6} s^{-1}$$

$$a = -\gamma_2 (V - V_{bg})|V - V_{bg}|$$
$$\gamma_2 = 2.36(\pm 1.03)\times 10^{-12} m^{-1}$$

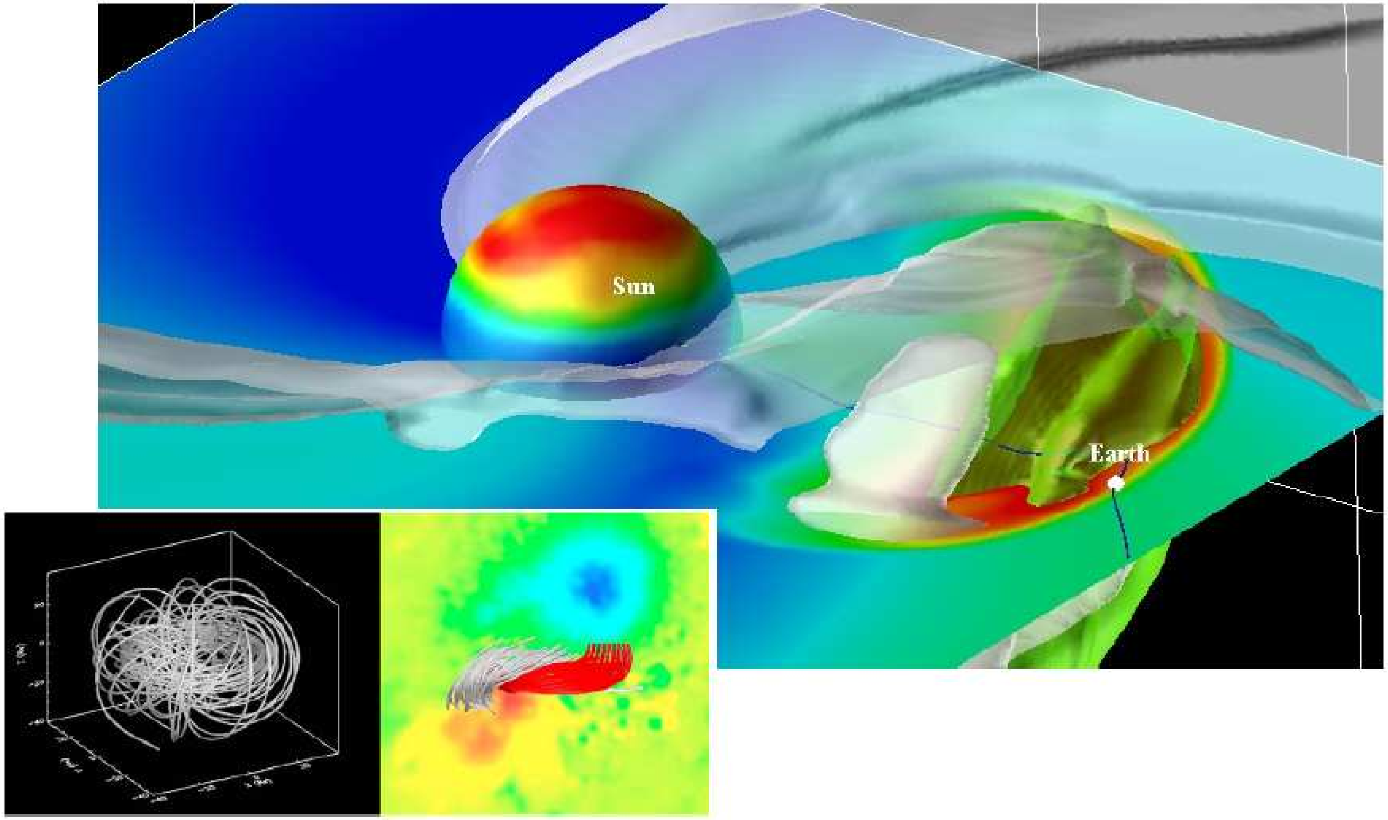
II. Case Study

2-1. Influence of Magnetic field on the Interplanetary Propagation of CMEs

2-2. Evaluation of CME Speed Estimation

2-1. 3-D MHD Simulation for the CME Propagation

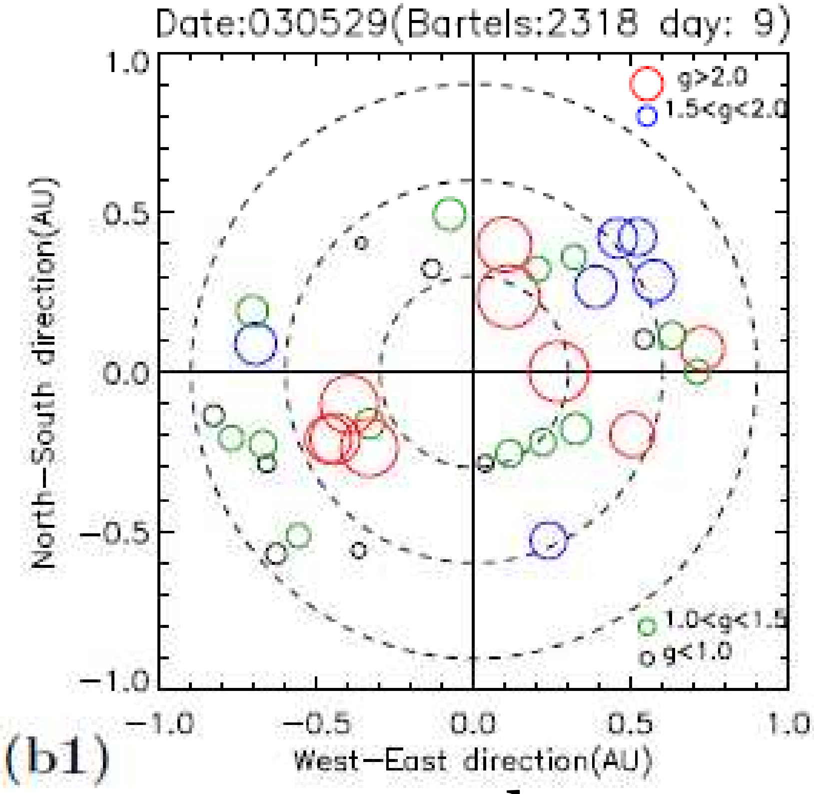
- Simulation of CMEs with a magnetic tours [Shiota and Kataoka, JpGU meeting, PEM05-38, 2013]
- Distance：$25\ R_s \leqq R \leqq 425\ R_s$ ($1\ AU = 215\ R_s$)
- Consider a drag force by the interaction with the solar wind and a driving force by the internal magnetic field.



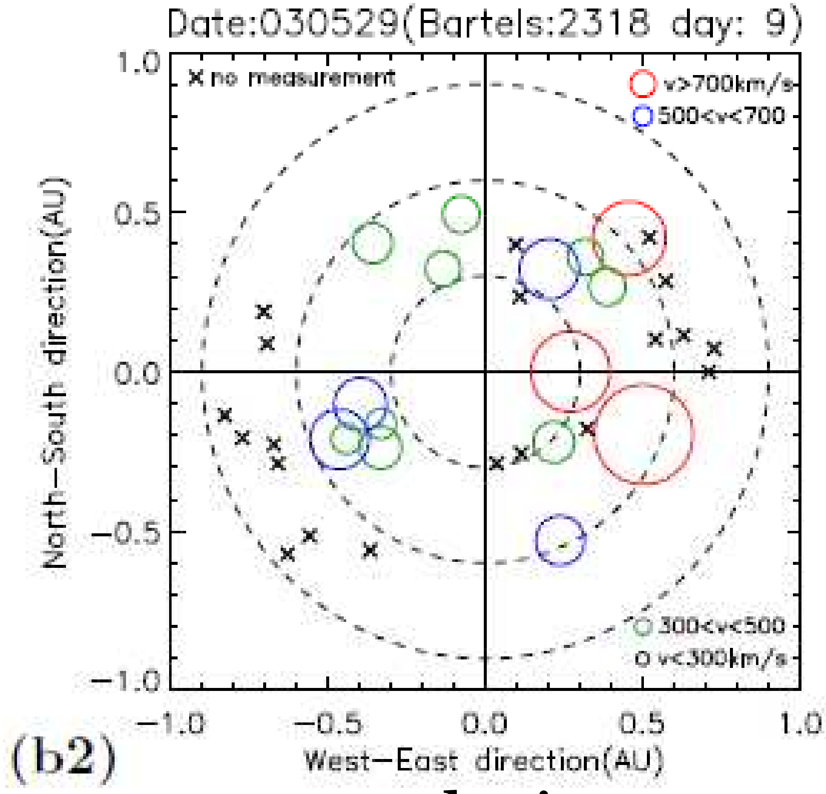
[Shiota and Kataoka, JpGU meeting, 2013]

- In this pdf, simulation results are omitted because we will write a paper for them.

2-2. Comparison between g-map and V-map: the 28 May 2003 CME



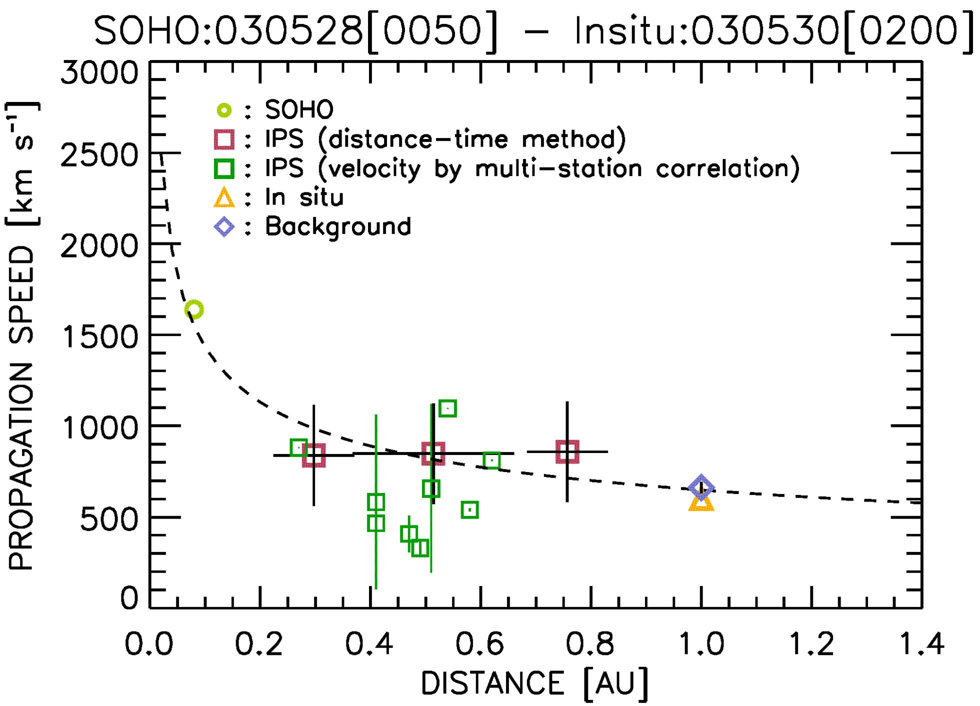
g-value
(single-station measurement)

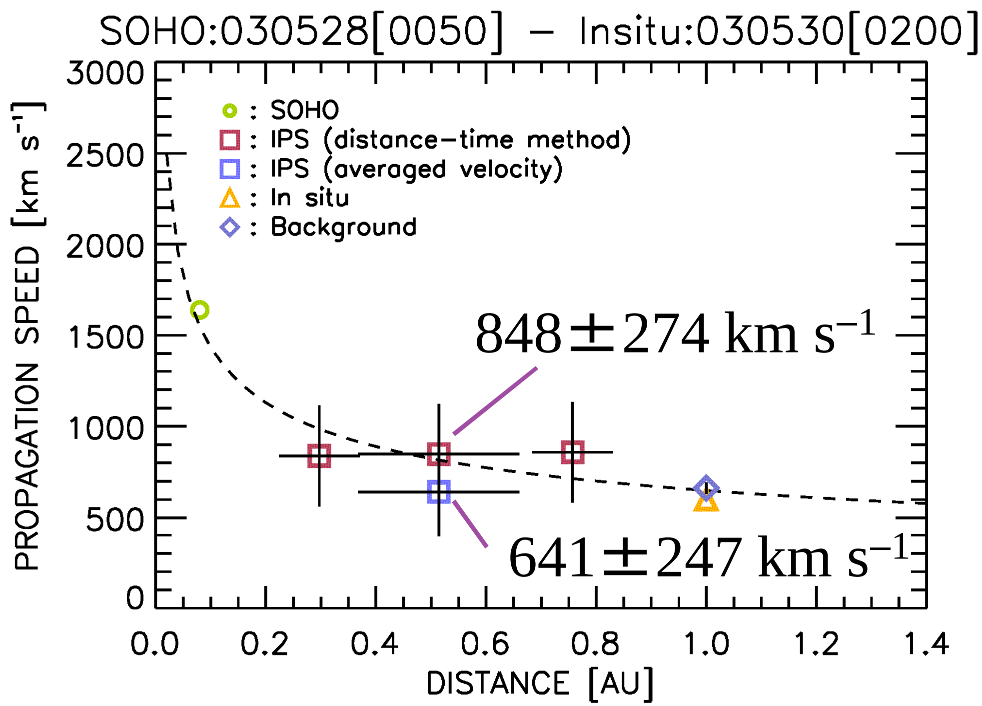


Velocity
(multi-station correlation)

- We choose radio sources measured both an enhanced g-value and velocity, and then estimate the CME speed using them.

2-2. Comparison between two methods of CME Speed Estimation: the 28 May 2003 CME





- CME speeds calculated using data of distance and time are somewhat larger than those derived from multi-station correlation.

Summary and Conclusions

I. Statistical Study

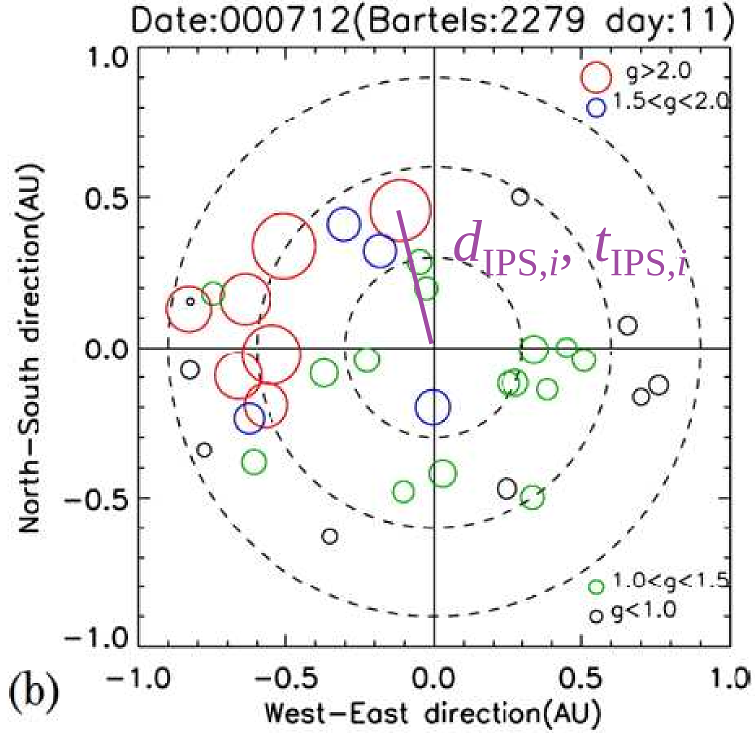
- We identified 46 CMEs using SOHO/LASCO, IPS, and *in-situ* observations during 1997 – 2011.
- For fast and moderate CMEs, a linear equation $a = -\gamma_1(V - V_{bg})$ with $\gamma_1 = 6.51\ (\pm 0.23) \times 10^{-6}\ s^{-1}$ is more appropriate than a quadratic one to describe their interplanetary propagation.
- For slow CMEs, we need to identify more events and then examine their propagation carefully.

II. Case Study

- We found from the comparison with a MHD simulation that the best-fit parameters (the angular width and strength of internal magnetic field) are different for each CME.
- CME speeds calculated using data of distance and time are somewhat larger than those derived from multi-station correlation for the 28 May 2003 event.

Calculation of CME radial speeds

- Reference distances $R_{1,2}$ and speeds $V_{1,2}$



SOHO-IPS: $R_1 = \frac{1}{n}\sum_{i=1}^{n}\frac{d_{\mathrm{SOHO}} + d_{\mathrm{IPS},\,i}}{2}$ $\quad V_1 = \frac{1}{n}\sum_{i=1}^{n}\frac{d_{\mathrm{IPS},i} - d_{\mathrm{SOHO}}}{t_{\mathrm{IPS},i} - t_{\mathrm{SOHO}}}$

IPS-ACE: $R_2 = \frac{1}{n}\sum_{i=1}^{n}\frac{d_{\mathrm{IPS},\,i} + d_{\mathrm{ACE}}}{2}$ $\quad V_2 = \frac{1}{n}\sum_{i=1}^{n}\frac{d_{\mathrm{ACE}} - d_{\mathrm{IPS},i}}{t_{\mathrm{ACE}} - t_{\mathrm{IPS},i}}$

Here, t_{SOHO} is CME appearance time, d_{SOHO} is Minimum radius of LASCO C2 F.O.V, P-point distance d_{IPS} and observation time t_{IPS} for a $g \geqq 1.5$ radio source, t_{ACE} is ICME detection time at ACE, and $d_{\mathrm{ACE}} \sim$ 1AU

Calculation of CME accelerations

From speeds $v_{1,2}$ at reference distances $r_{1,2}$, CME appearance time t_{SOHO}, mean near-Sun CME speed V_{SOHO}, observation time t_{IPS} for a $g \geqq 1.5$ radio source, ICME detection time t_{ACE}, and mean near-Earth ICME speed V_{ACE}

SOHO-IPS: $$a_1 = \frac{1}{n}\sum_{i=1}^{n} \frac{v_{\mathrm{IPS},i} - V_{\mathrm{SOHO}}}{t_{\mathrm{IPS},i} - t_{\mathrm{SOHO}}}$$

Here $$v_{\mathrm{IPS},i} = \frac{v_{1,i} + v_{2,i}}{2}$$

IPS-ACE: $$a_1 = \frac{1}{n}\sum_{i=1}^{n} \frac{V_{\mathrm{ACE}} - v_{\mathrm{IPS},i}}{t_{\mathrm{ACE}} - t_{\mathrm{IPS},i}}$$