Working Group 2 – Theory **Summary**

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WG 2: Overview

- **Objective**: To understand the structure and evolution of CMEs as well as their origin and their magnetic rope structure. Specifically:
  - What is the origin of Bz and how can it be modeled?
  - Are CMEs deflected in the heliosphere?
  - How do ambient conditions affect CME structure, propagation, and dynamics?
  - How long does the Lorentz force dominate over aerodynamic drag?
  - How can we estimate the drag parameter and/or dimensionless drag coefficient?

- **Approach**: Compare results from different analytic and numerical models with measurements, such as transit time to 1AU, kinematics, impact speed, impact magnetic field, etc.

WG 2 – ACTIVITY REPORT

- ***Main progresses where theoretical aspects were included:***

1. Drag effect related issues
   - DBM applied to events from the “ISEST list”
   - Comparison of analytic (DBM) and numerical (ENLIL) model (e.g., Vrsnak et al., ApJS 213, 21, 2014)
   - Estimation of CME “true” mass (e.g., Bein et al., ApJ, 768, 31, 2013; Feng et al., JGR, in revision, 2014)
   - CME Propagation: Where does Aerodynamic Drag 'Take Over'? (Sachdeva, Nishtha; Subramanian, Prasad; Colaninno, Robin; Vourlidas, Angelos, Ap. J., 2015)
   - Heliospheric Propagation of Coronal Mass Ejections: Drag-based Model Fitting (Žic, T.; Vršnak, B.; Temmer, M., Ap. J. Suppl. Ser., 2015)
   - Dynamics of CMEs in the LASCO Field of View (Michalek, G.; Gopalswamy, N.; Yashiro, S.; Bronarska, K., Sol. Phys., 2015)
2. CME deflection/rotation
   - Deflection --- Observational evidence and kinetic model (Wang et al., JGR, 119, 5117, 2014)
   - 3-D evolution revealing rotation (Isavnin et al., SoPh, 2013; 2014)
   - Global Trends of CME Deflections Based on CME and Solar Parameters (Kay, C.; Opher, M.; Evans, R. M., Ap. J. Lett., 2015)
   - The Heliocentric Distance where the Deflections and Rotations of Solar Coronal Mass Ejections Occur (Kay, C.; Opher, M., Ap. J. Lett., 2015)

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- ***Main progresses where theoretical aspects were included (continue):***

3. Interacting structures
   - CME-CME interactions (e.g., Shen et al., GRL, 40, 1457, 2013; Temmer et al., ApJ 785, 85, 2014; Maricic et al., SoPh 289, 351, 2014; Shanmugaraju et al., SoPh 289, 339, 2014; Mishira et al., ApJ, 2014)
   - Shock-CME interactions (RAL/Oxford workshop)
   - An Analytical Model of Interplanetary Coronal Mass Ejection Interactions (Niembro, T.; Cantó, J.; Lara, A.; González, R. F., Ap. J., 2015)
4. MC fitting technique and related
   - Investigating plasma motion of magnetic clouds at 1 AU through a velocity-modified cylindrical force-free flux rope model (Wang et al., JGR, 2015)
   - Radial Evolution of a Magnetic Cloud: MESSENGER, STEREO, and Venus Express Observations (Good, S. W.; Forsyth, R. J.; Raines, J. M.; Gershman, D. J.; Slavin, J. A.; Zurbuchen, T. H., Ap. J., 2015)
   - Geometrical Relationship Between Interplanetary Flux Ropes and Their Solar Sources (Marubashi, K.; Akiyama, S.; Yashiro, S.; Gopalswamy, N.; Cho, K.-S.; Park, Y.-D., Solar Physics, 2015)

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- ***Main progresses where theoretical aspects were included (continued):***

5. Background solar wind
   - Spatially/temporally variable solar wind environment (e.g., Rollett et al., ApJL 790, 6, 2014)
   - On the role played by magnetic expansion factor in the prediction of solar wind speed

   (Pete Riley, Jon A. Linker, C. Nick Arge, Space Weather Journal, 2015)

PLANS

- ***Main objectives/topics to be pursued:***
  - Drag effect related issues
    - Comparisons with MHD solutions?
  - CME deflection/rotation
  - Interacting structures
  - MC fitting technique and related
  - Background solar wind
- **Start research on: *How to model Bz ?!***
  - Theory/numerical modelling
  - Laboratory experiments for some topics

Recent progress: Example

- HELIOSPHERIC PROPAGATION OF CORONAL MASS EJECTIONS: DRAG-BASED MODEL FITTING by Zic et a

$$E(\Gamma, w_\infty; R_0, v_0) = \sum_{i=0}^{N} [v_i - v(\{\Gamma, w_\infty; R_0, v_0\}, R_i)]^2$$

$$F = F_\mathrm{L} - F_\mathrm{g} + F_\mathrm{d}.$$

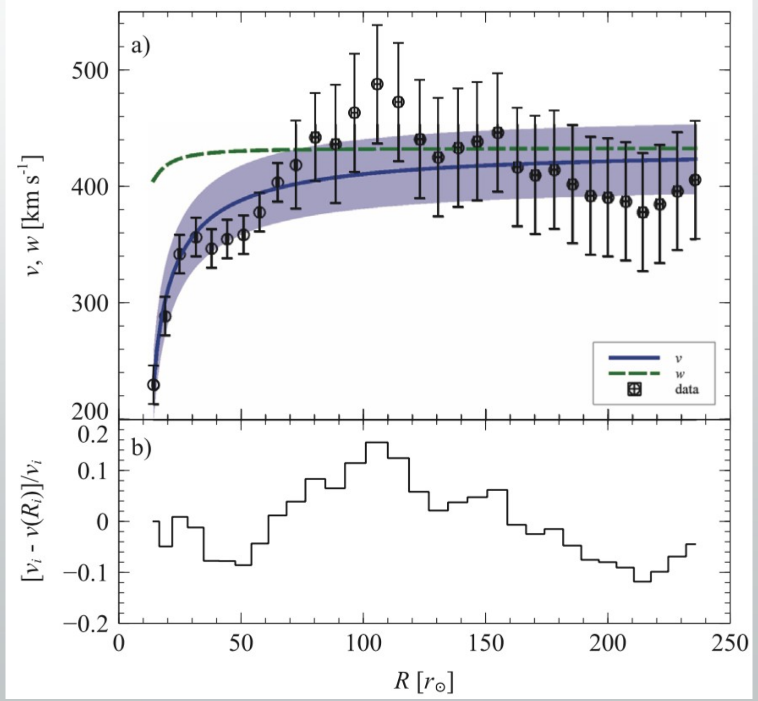
$$v(R)\,\frac{\mathrm{d}v(R)}{\mathrm{d}R} = -\gamma(R)\,[v(R) - w(R)]\,|v(R) - w(R)|$$

$$F_\mathrm{d} = -c_\mathrm{d}\,A\rho(v - w)|v - w|$$

$$a_\mathrm{d} = -\gamma(v - w)|v - w|$$

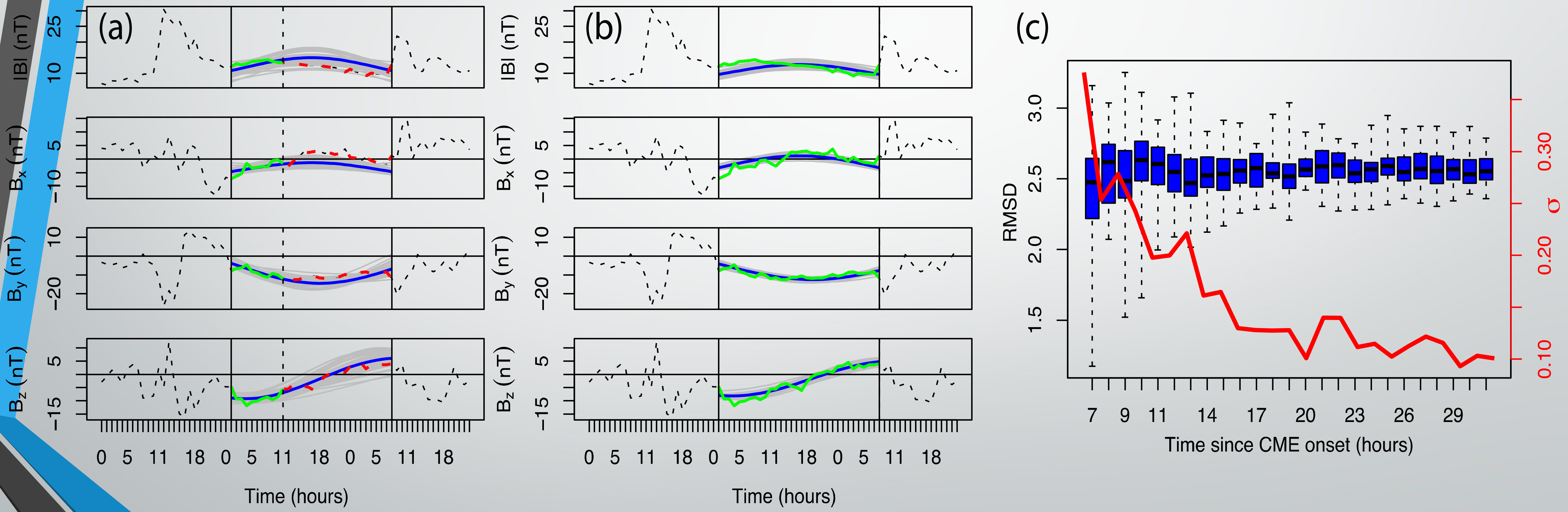
$$\gamma = c_\mathrm{d}\frac{A\rho}{M}$$

$$\gamma(R) = \gamma_\infty \frac{w_\infty}{w(R)}$$



WG2 presentations

- **How to Predict Bz?**(Pete Riley)



WG2 presentations

- **Coronal Mass Ejections: A Journey From Its Origin to Its Transport in the Interplanetary Medium** (Andrea Borgazzi, Invited)

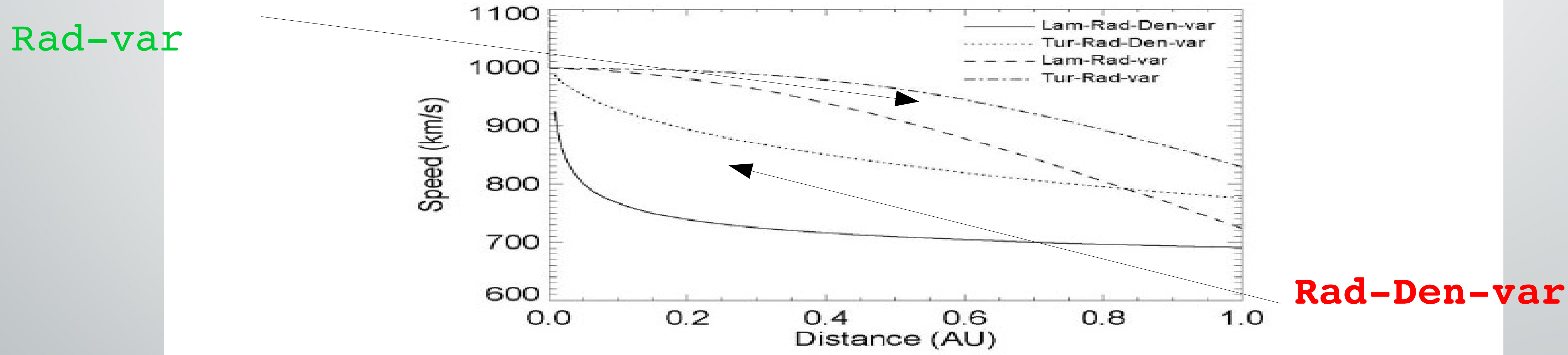
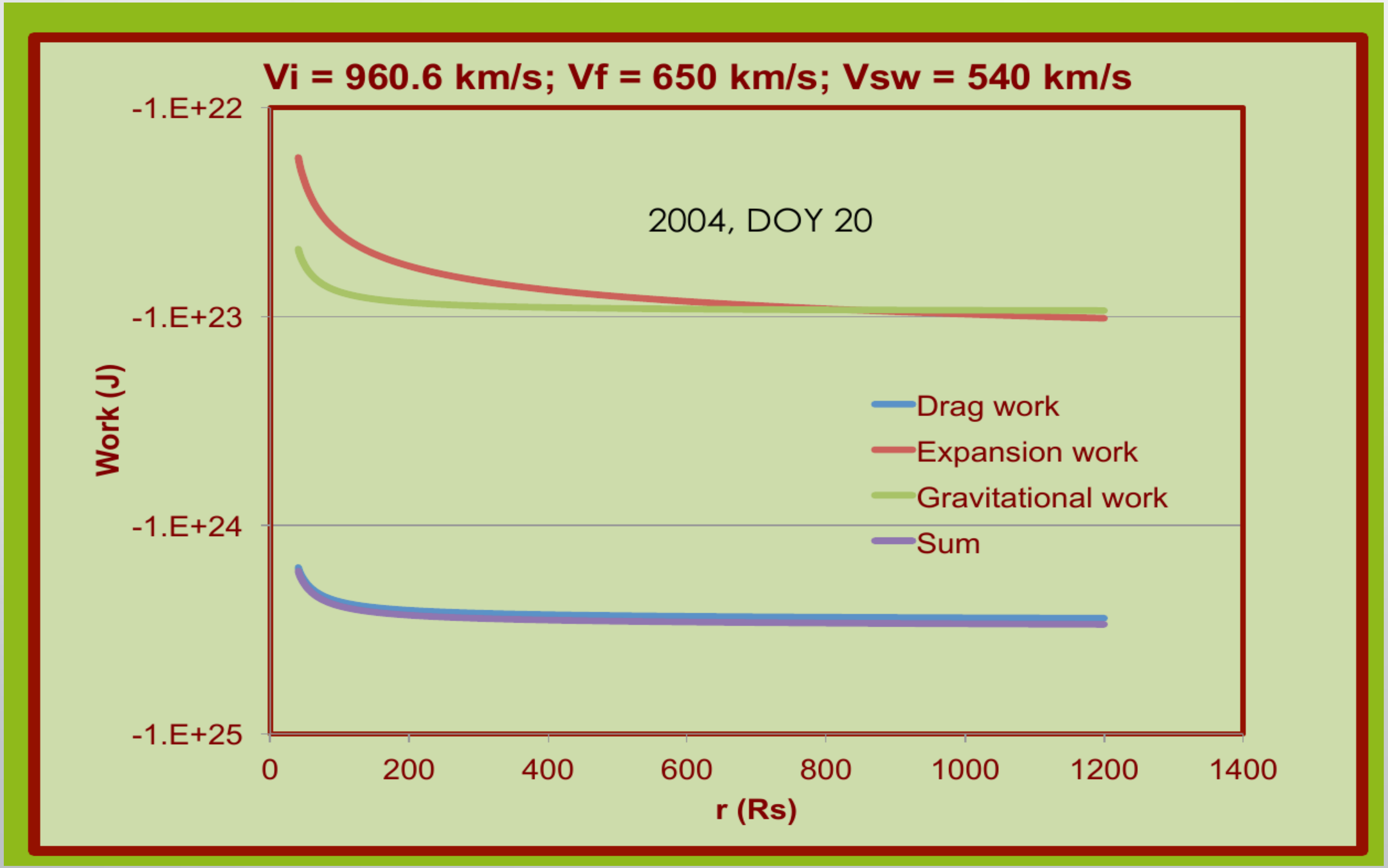


FIGURE 6.20 - ICME speed versus distance for the four models analyzed in this work. a) laminar regime considering variability in ICME radius (Eq. 4.9) and $\mu = 0.175\ g/cm \cdot s$ (dashed line). b) turbulent regime considering variability in ICME radius (Eq. 4.10) and $C_d = 5 \times 10^4$ (dot-dashed line). c) laminar regime considering variability in ICME radius and SW density (Eq. 4.16) and $\nu = 8.75 \times 10^{20}\ cm^2/s$ (continuous line). and d) turbulent regime considering variability in ICME radius and SW density (Eq. 4.13) and $C_d = 1.1 \times 10^5$ (dot line).

WG2 presentations

- **Balance of Energy in a CME** (Héctor J. Durand Manterola)



WG2 presentations

- **Plasma Interaction Processes That Lead to Viscous Forces in the Solar Wind** (Héctor Pérez de Tejada)

CONTENTS

Viscous forces suitable for particle-particle (coulombian) and wave-particle (magnetic turbulent) interactions in the solar wind.

The solar wind interaction with planetary ionospheres

I - Transport of solar wind momentum to the Venus upper ionosphere (discussion of measurements and their interpretation).

II - Calculation of viscous forces at the region of interaction between the solar wind and the Venus ionosphere (wave-particle interactions in the solar wind, and particle-particle collisions in the Venus upper ionosphere).

WG2 presentations

- **Synthetic Transits of Plasma Sheaths and Shocks: A Pathway to Predict in-situ Arrivals of Shock Waves Associated With Fast Halo CMEs** (Pedro Corona Romero*, J. A. González Esparza, V. de la Luz, J. C. Mejía Ambriz, L. X. González)

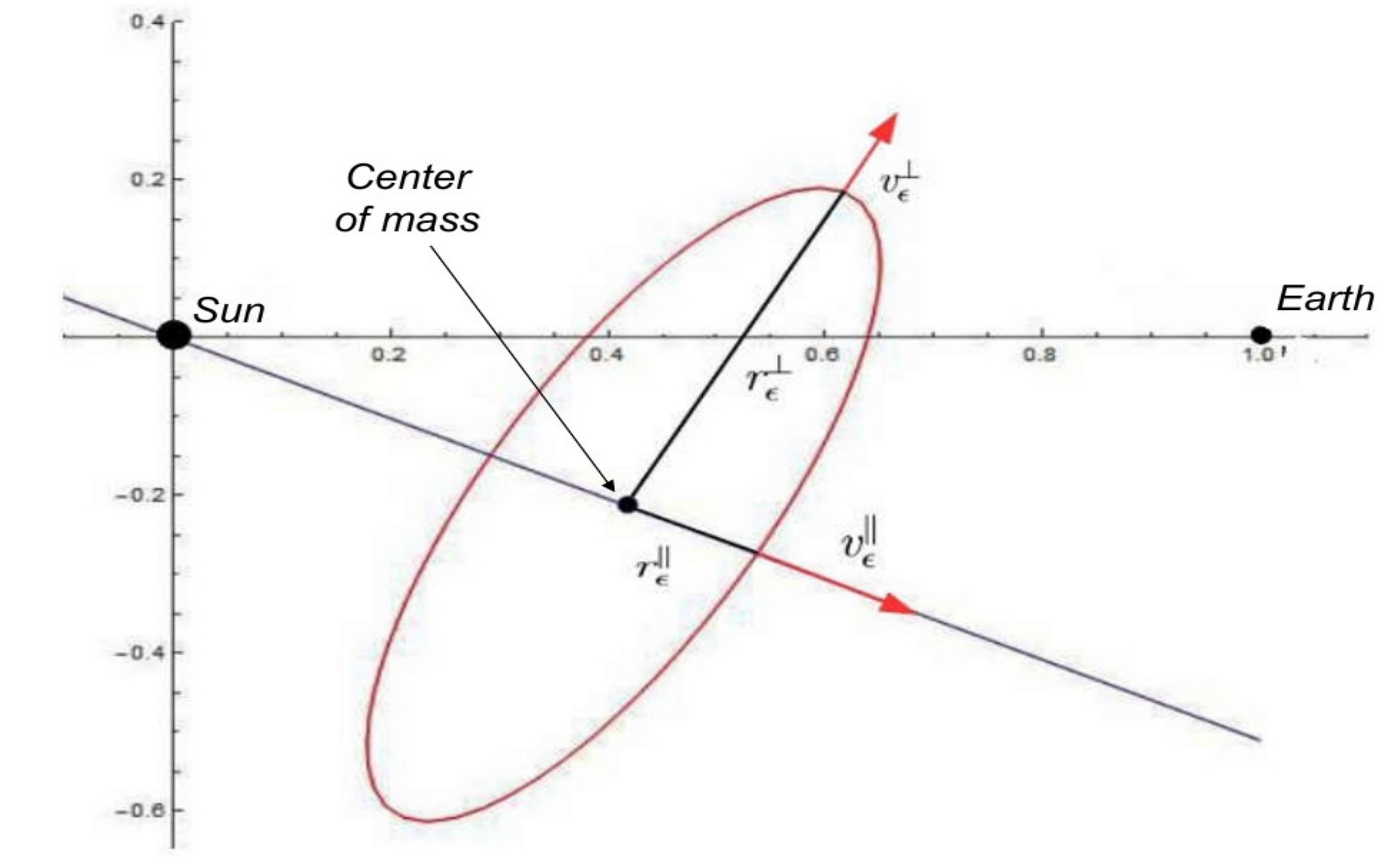
WG2 presentations

- We developed an **analytical method** to approximate:
  1) **arrival of shocks** associated with halo CMEs, and
  2) **in-situ transit** profiles (synthetic transits) of plasma sheath
- All the method's inputs are initial data from the event, save the quotient between initial densities of CMEs and ambient solar wind.
- This is an experimental tool of SCiESMEX for space weather forecasting.

WG2 presentations

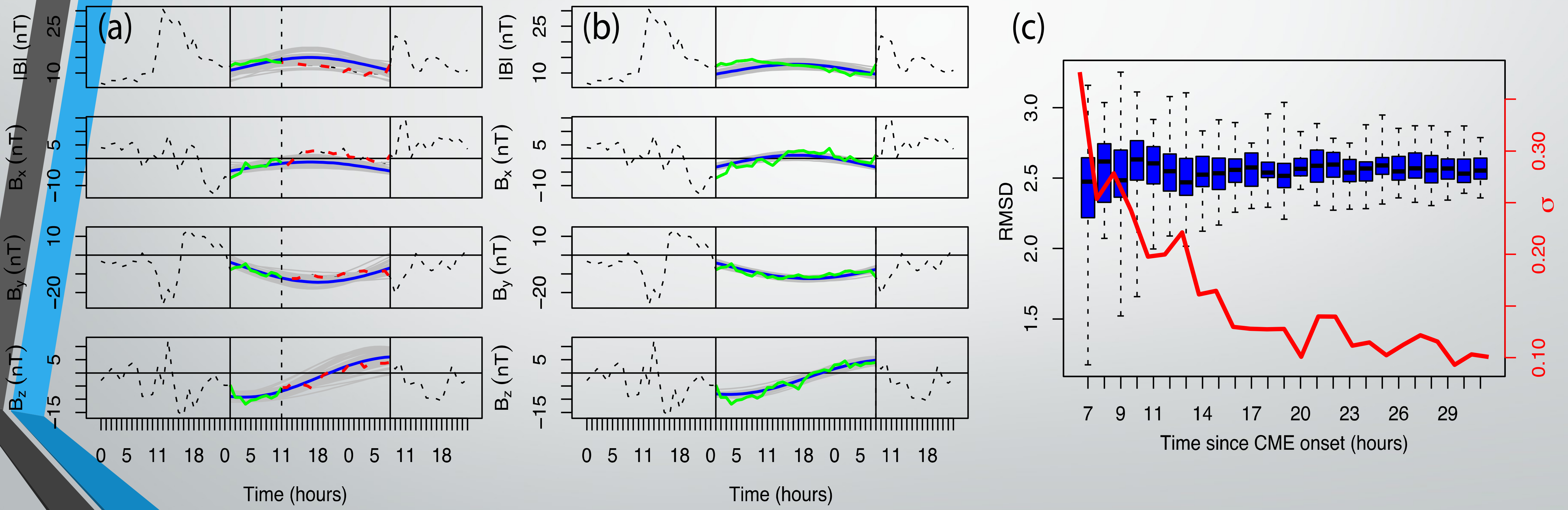
- **Dynamics of Coronal Mass Ejections in the Interplanetary Medium in Two Dimensions** (Juan Carlos González Marin)

2) Ellyptical form for the leading edge of the CME and profiles for the position and the speed for any point of it.



WG2 presentations

- **How to Predict Bz?**(Pete Riley)

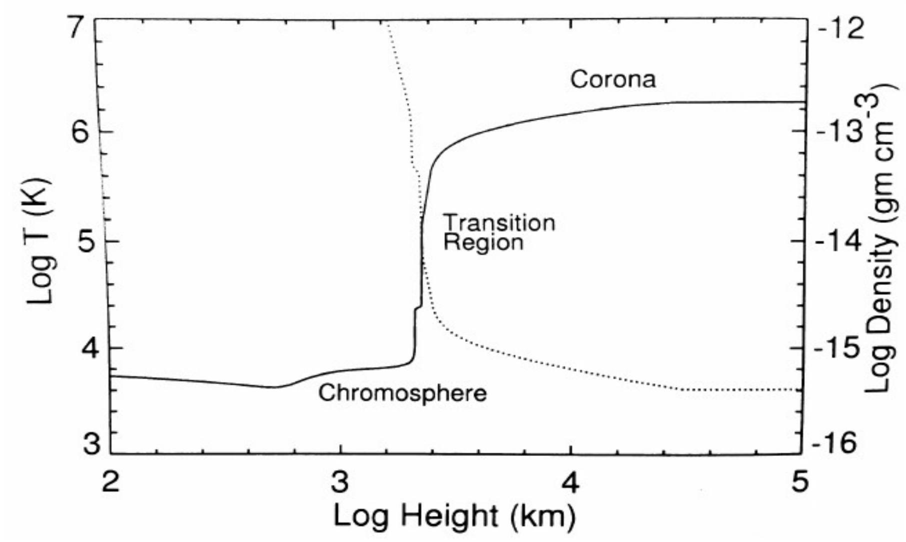


WG2 presentations

- **Study of the Transport of Heat in the Solar Corona** (Diana Gamborino Uzcanga*, J. Martinell Benito, D. del Castillo Negrete)

WG2 presentations

Abstract



-Solar Corona heating mechanisms still not clear.

- Energy released mainly in AR - propagated to other regions - maintain Corona at observed T.

- Global heat transport influenced by complex $\vec{B}$ geometry that couples distant regions of Corona.

- Produce nonlocal effects in the transport.

- EUV images - AIA/SDO.Three cases: (a) following an explosive event, (b) five hours before the explosive event, same AR and (c) Quiet Sun region.

- SolarSoft - T Maps- full solar disk.

- Regions of interest - selected and analyzed with POD methods.

- (1) Topos-Chronos: Energy cascade process determined -subdiffusion.

- (2) GLRAM: $w \sim t^{\gamma}$. W found $\gamma < 1$: subdiffusion.

Summary

- WG2 has made good progress on the goals set at the previous workshop
- Aerodynamic drag continues to be a focus point for study
- Modeling and theory complementary and overlapping concepts – perhaps the distinction is that WG2 shouldn't focus on complex 3-D models, but rely on more idealized approaches to "explain" phenomena
- More work needs to be done regarding the relative contribution of the drag force and other forces as the CME leaves the Sun
- A crucial question for this group could be: What are the underlying physical processes (kinetic) in the solar wind that give rise to the drag force?

Prediction of Bz remains an overarching goal for WG2