WORKING GROUP 2 - THEORY

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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)

WG 2 – ACTIVITY REPORT

- ***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)

WG 2 – ACTIVITY REPORT

- ***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

- HELIOSPHERIC PROPAGATION OF CORONAL MASS EJECTIONS: DRAG-BASED MODEL FITTING by Zic et al. (2015)

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

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

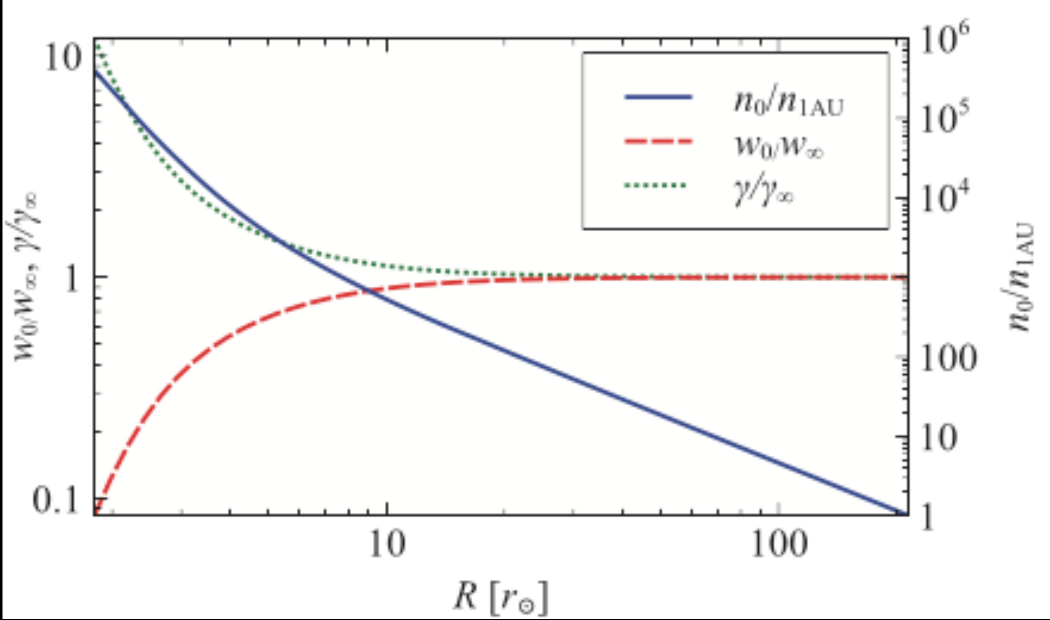
$$a_{\mathrm{d}} = -\gamma(v - w)|v - w|$$

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

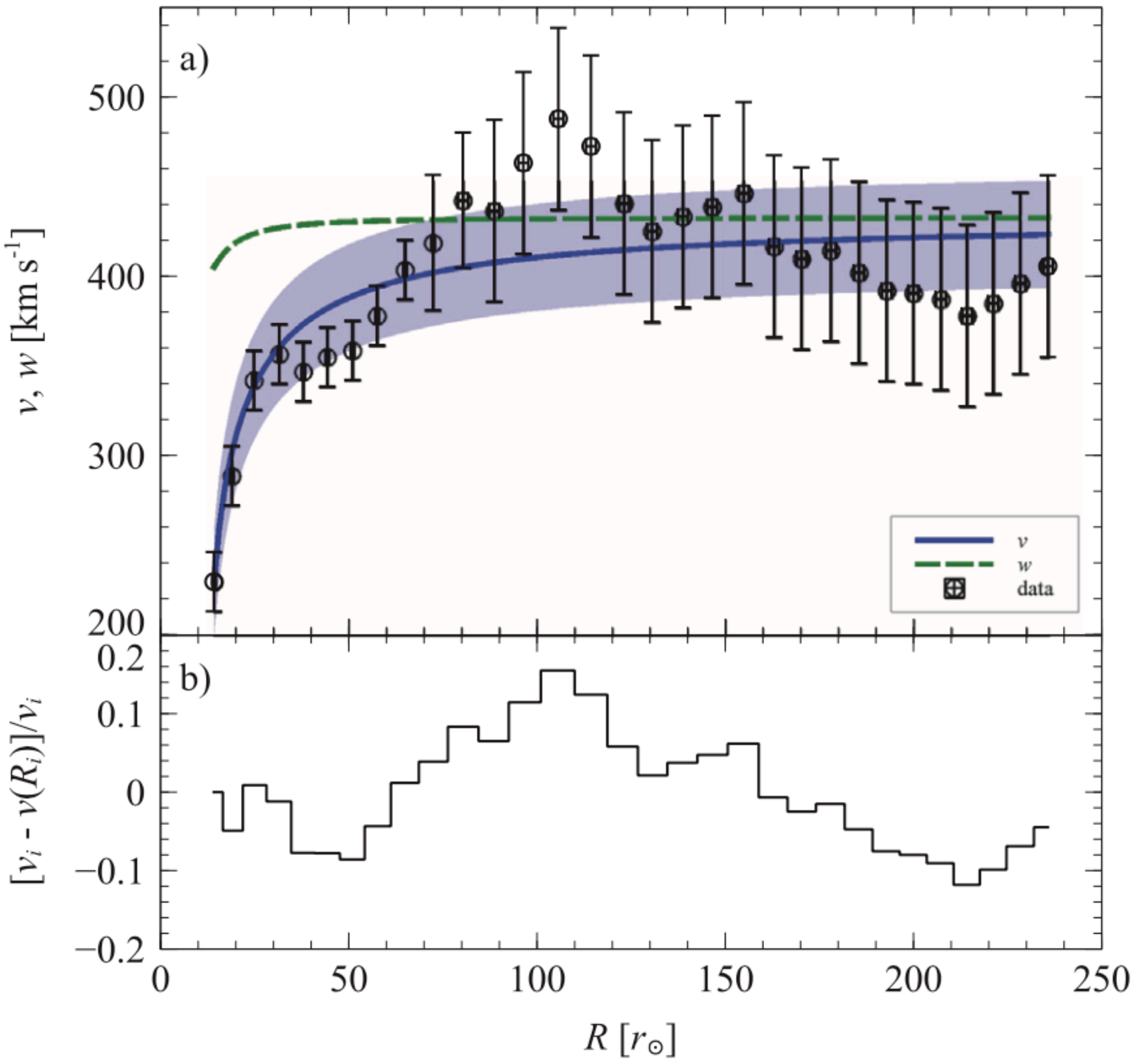
$$\gamma(R) = \gamma_\infty \frac{w_\infty}{w(R)}$$

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

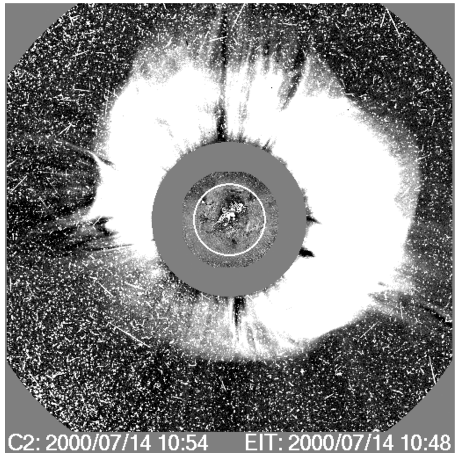
$$v(R) \frac{\mathrm{d}v(R)}{\mathrm{d}R} = -\gamma(R)\, [v(R) - w(R)]\, |v(R) - w(R)|$$

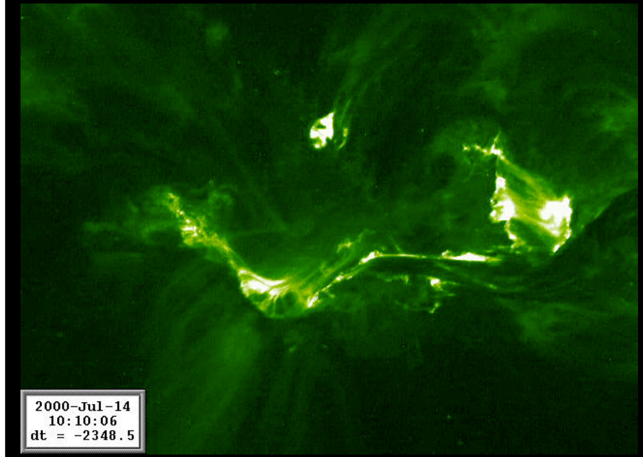


RECENT PROGRESS

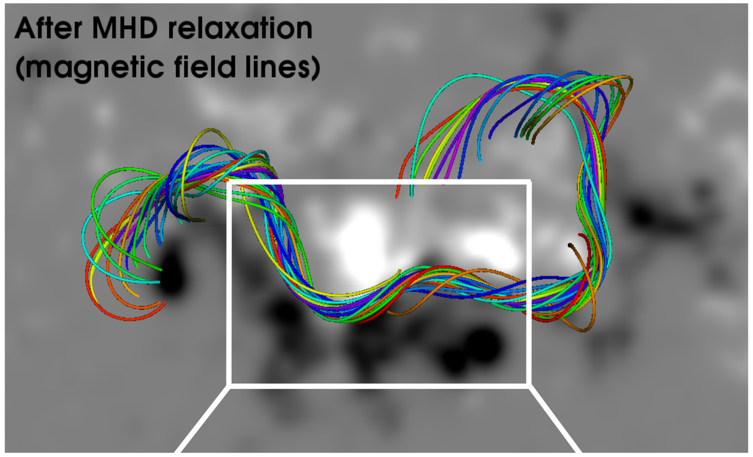


Thermodynamic MHD simulation of the Bastille Day event





TRACE 195 Å



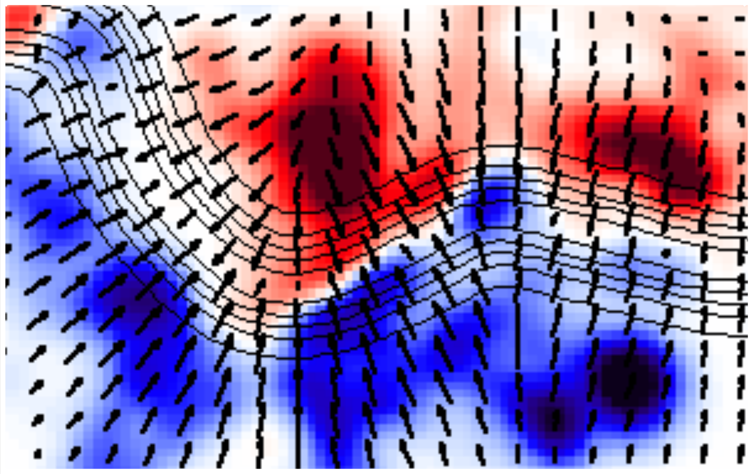
inserted flux rope

X5.7 flare & geo-effective halo CME on 2000 July 14

1.) calculate steady-state corona & solar wind

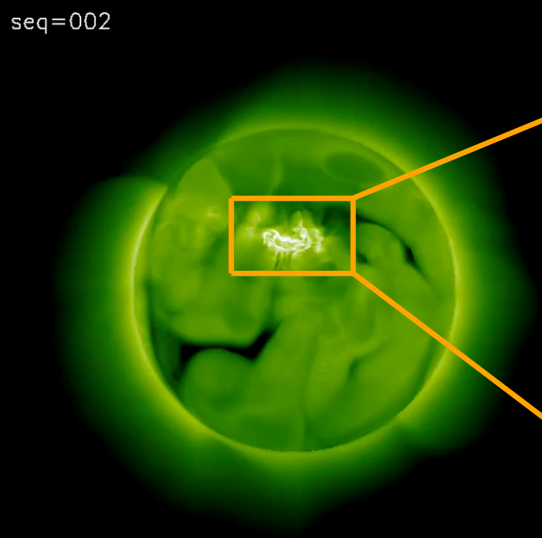
2.) construct stable flux rope in active region

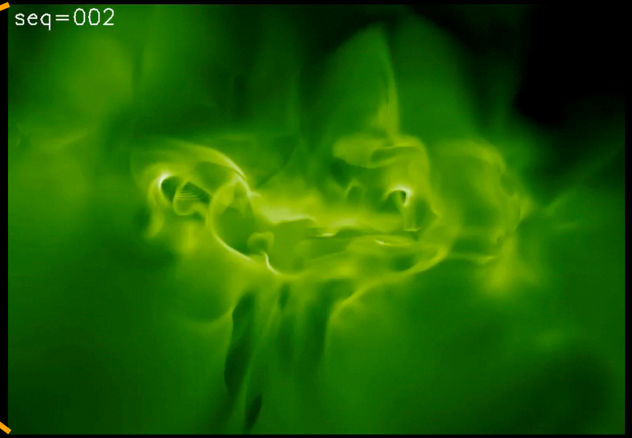
3.) trigger eruption by ad-hoc converging flows



converging flows

Thermodynamic MHD simulation of the Bastille Day event





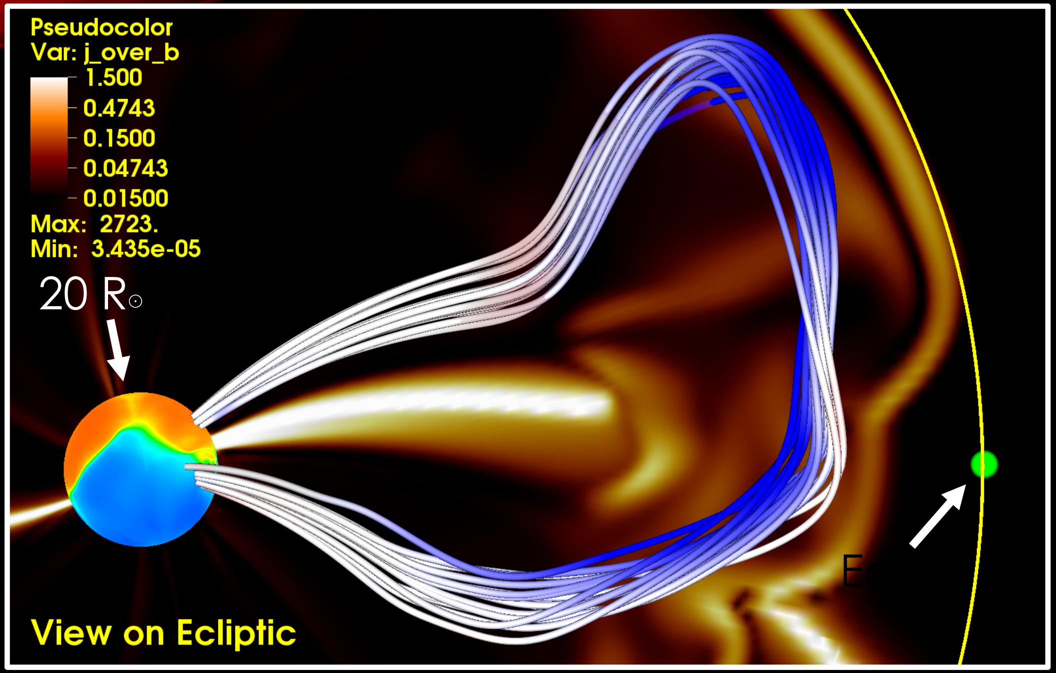
SOHO/EIT 195 Å
(active region)

SOHO/EIT 195 Å
(synthetic emission;
full-disk view)

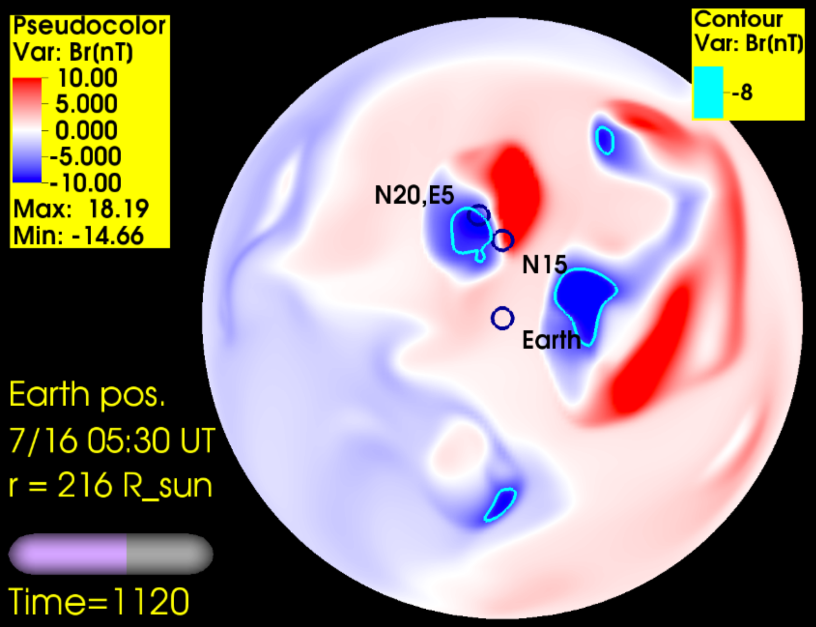
polarization brightness
running ratio
(synthetic emission;
3-20 solar radii)

- synthetic satellite images allow direct comparison with observations
- flare arcade and halo-CME morphologies qualitatively reproduced
- CME speed ≈ 1500 km/s & kinetic energy ≈ 4 x 10^{32} ergs

Heliospheric extension of the Bastille Day event



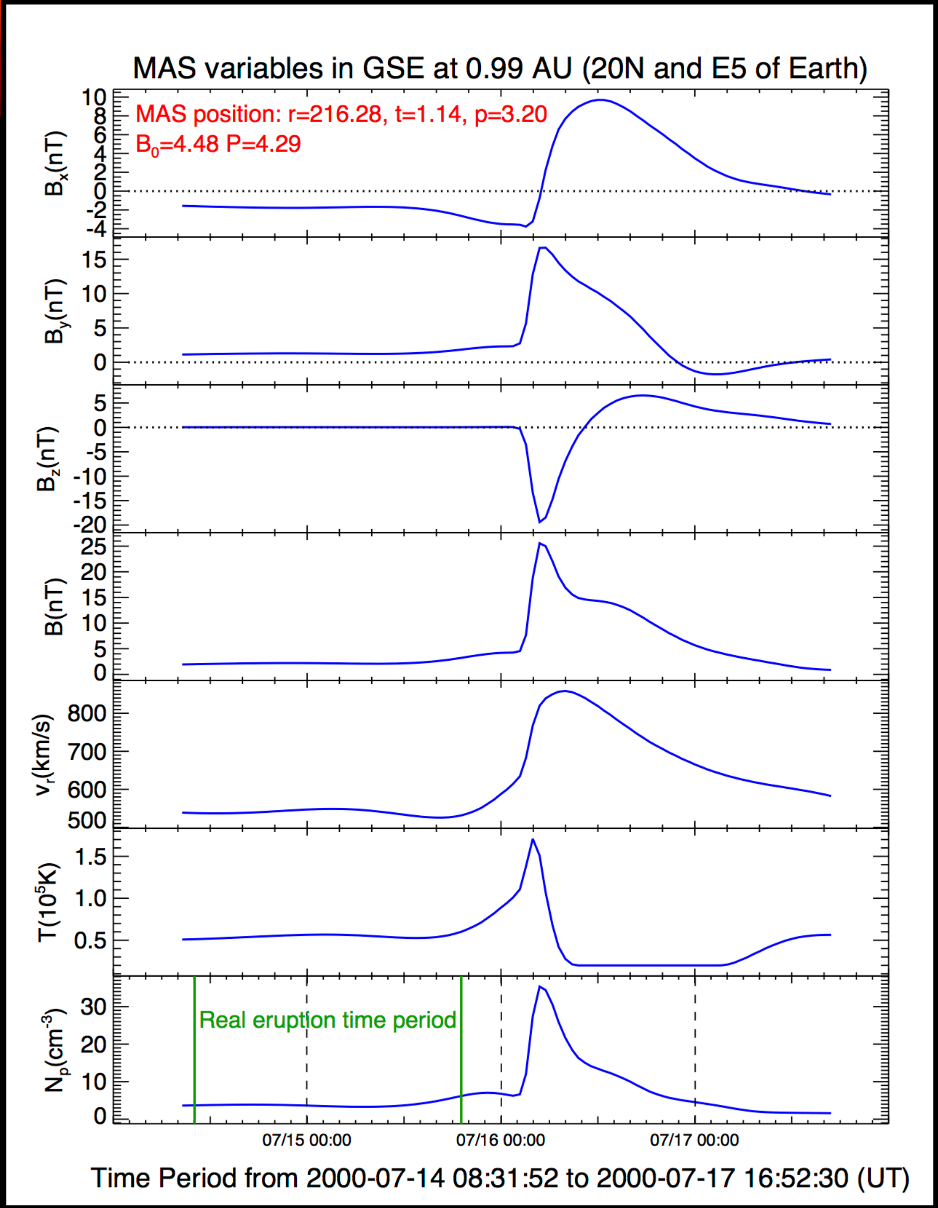
model ICME core & electric currents in ecliptic plane



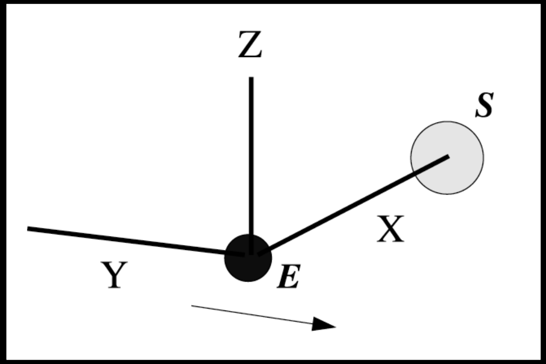
radial magnetic field at 1 AU

- flux-rope core structure preserved at 1 AU (still connected to surface)
- ICME arrives with rather scattered shape (non-synchronous eruption?)
- area of -Bz relatively small → difficult to match/predict

Heliospheric extension of the Bastille Day event



simulation data at 1 AU

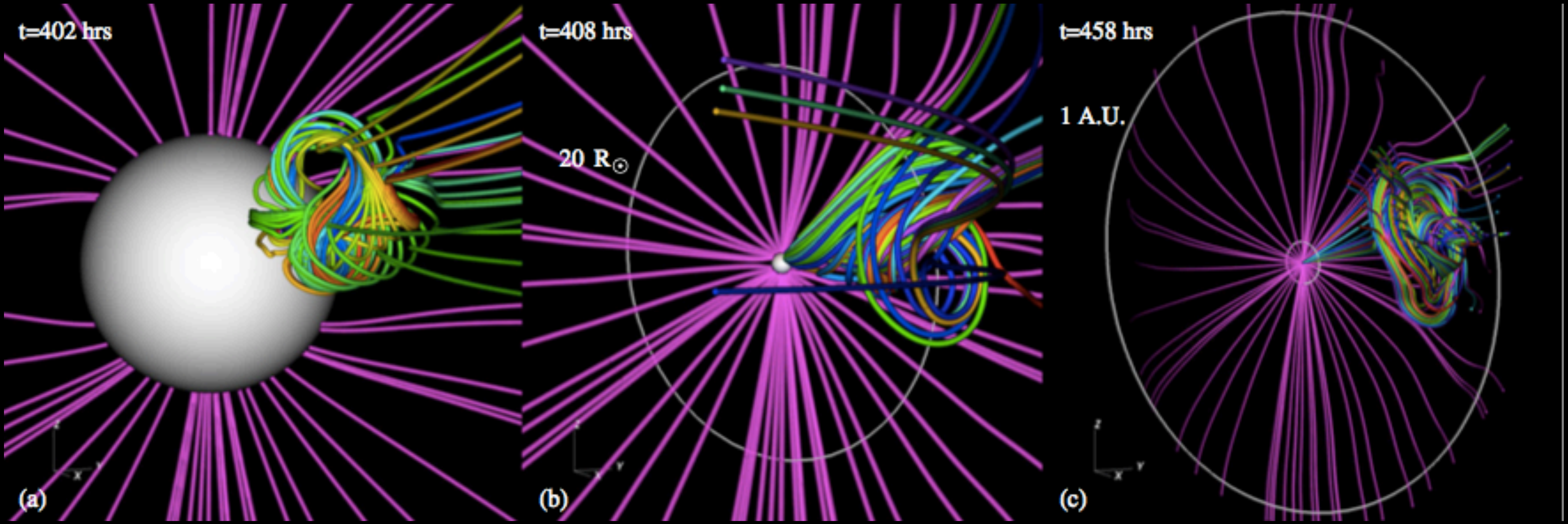


GSE coordinate system

- flux rope qualitatively reproduced
- B field strength too low (≈ factor 2)
- ICME too slow (≈ 6-8 h delay)

quantities at Earth very difficult to match with present models?

SPHEROMAKS IN THE SOLAR WIND?



HOW TO MODEL/PREDICT B_Z?

WHAT CAUSES NON-ZERO B_Z?

- **CMEs** (magnetic clouds/flux ropes) – inside and outside the ejecta
- **CIRs** (shearing flows, compressions, rarefactions)
- **W&T** (Waves and turbulence)
- *M*isc. effects – magnetic holes, PBSs, etc.
- ?

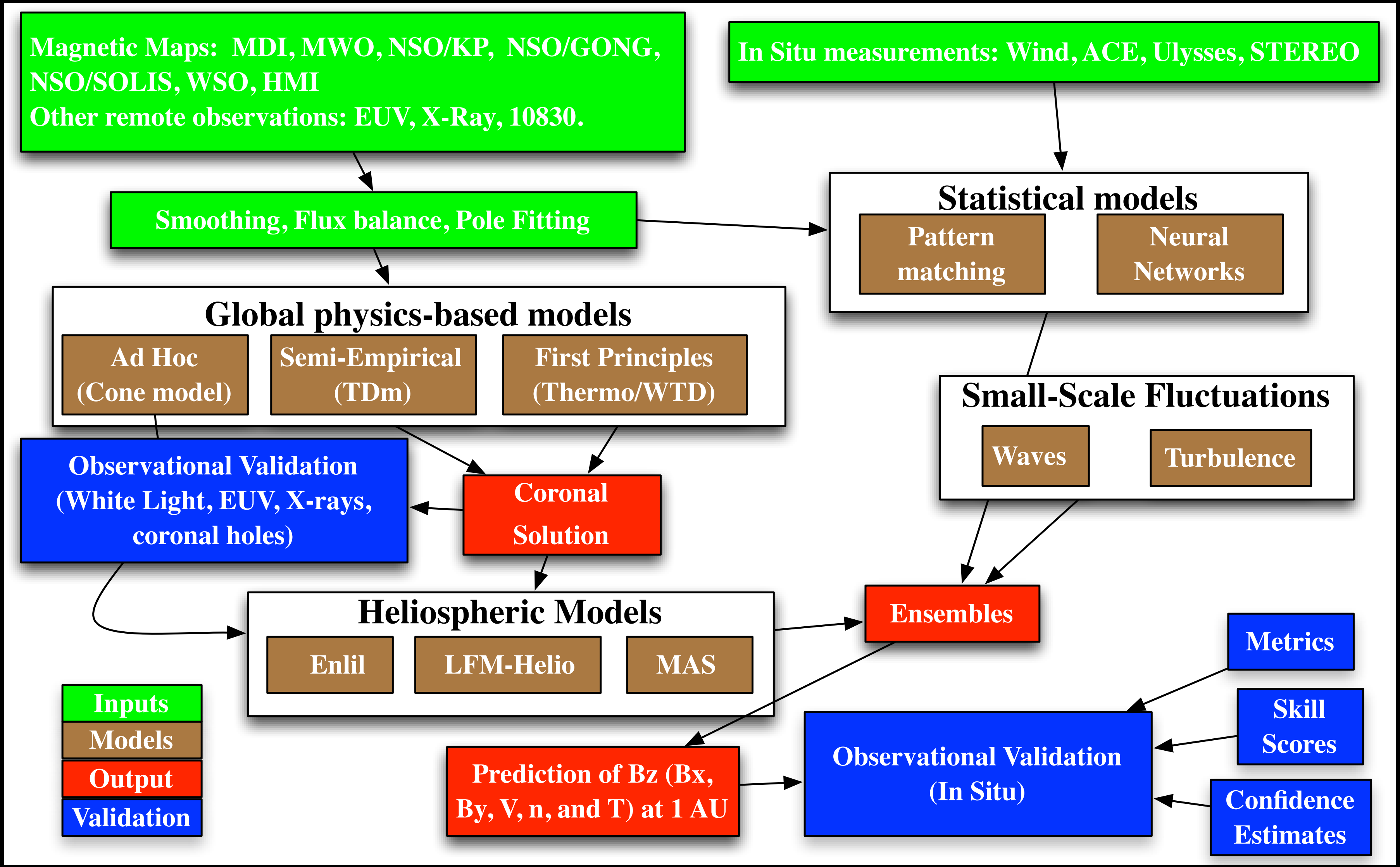
CURRENT "STATE OF THE ART" FOR PREDICTING B_Z…

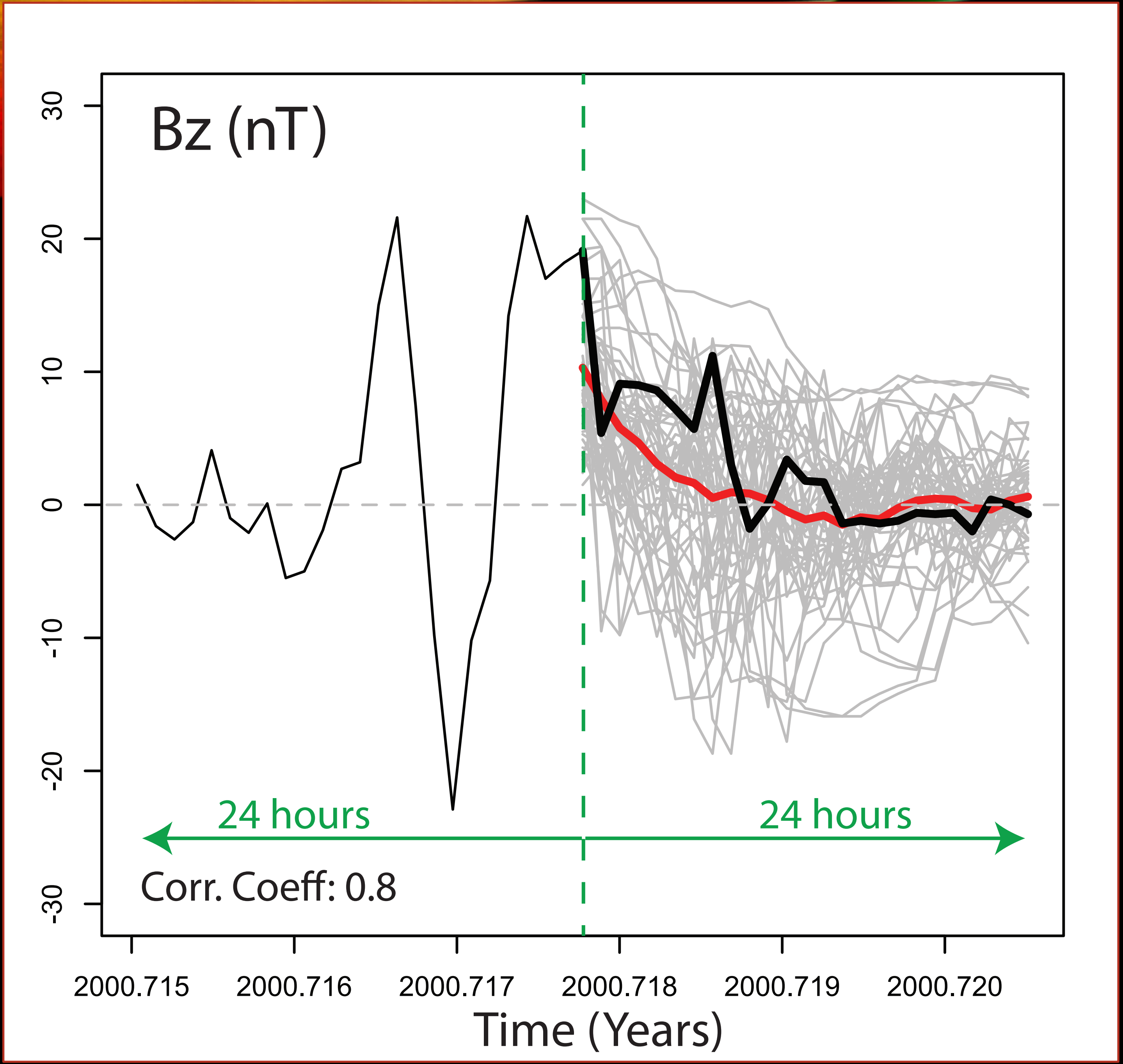
- No space weather prediction centre(er) currently makes B_Z forecasts
- Predictions schemes/websites are under development
- Arguably, persistence (B_Z=0) is the best forecast
- Current "bar" – *Savani et al.* (2015)

EXAMPLES OF TECHNIQUES FOR ESTIMATING BZ

- **Steady-state**
  1. CIRs
  2. Jackson technique
  3. Ulrich technique
  4. Waves turbulence
- **Transients**
  1. Flux ropes (large-scale, small-scale)
  2. Sheath regions of CMEs

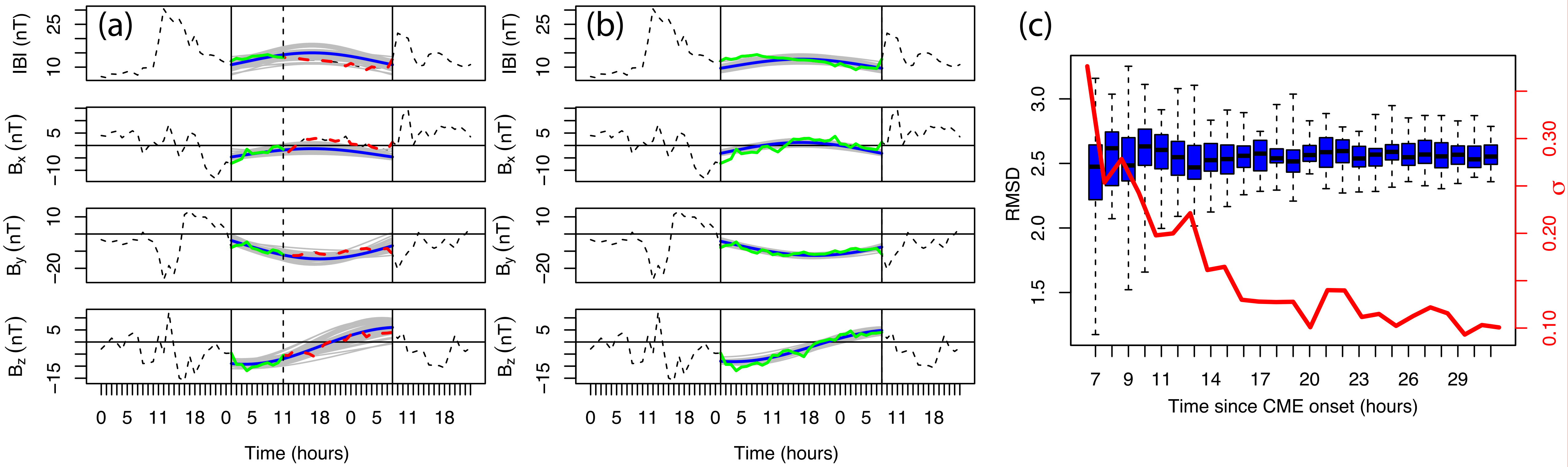
PROJECT ZED: PROPOSED METHODOLOGY



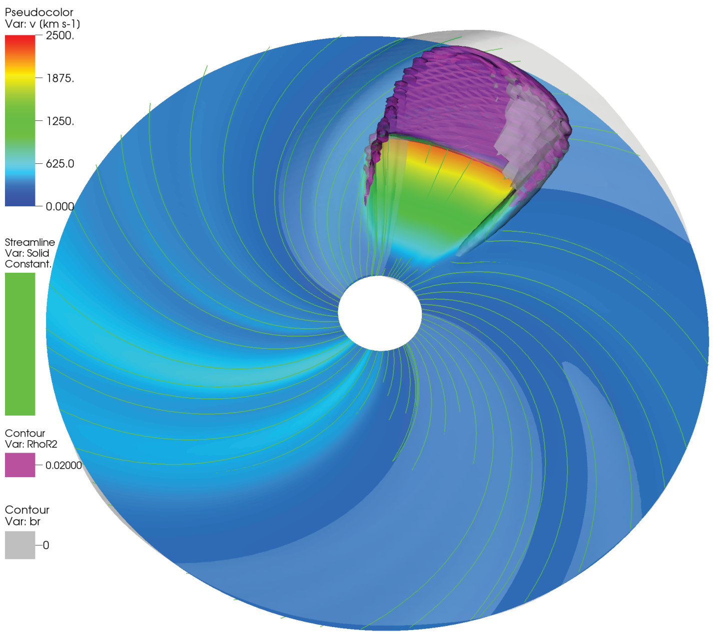


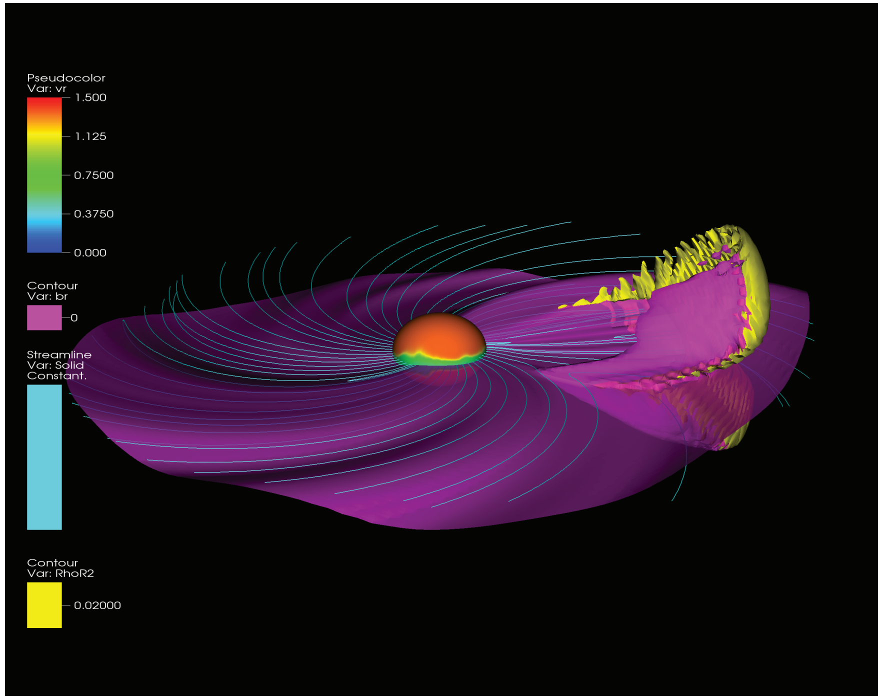
PATTERN MATCHING APPROACHES

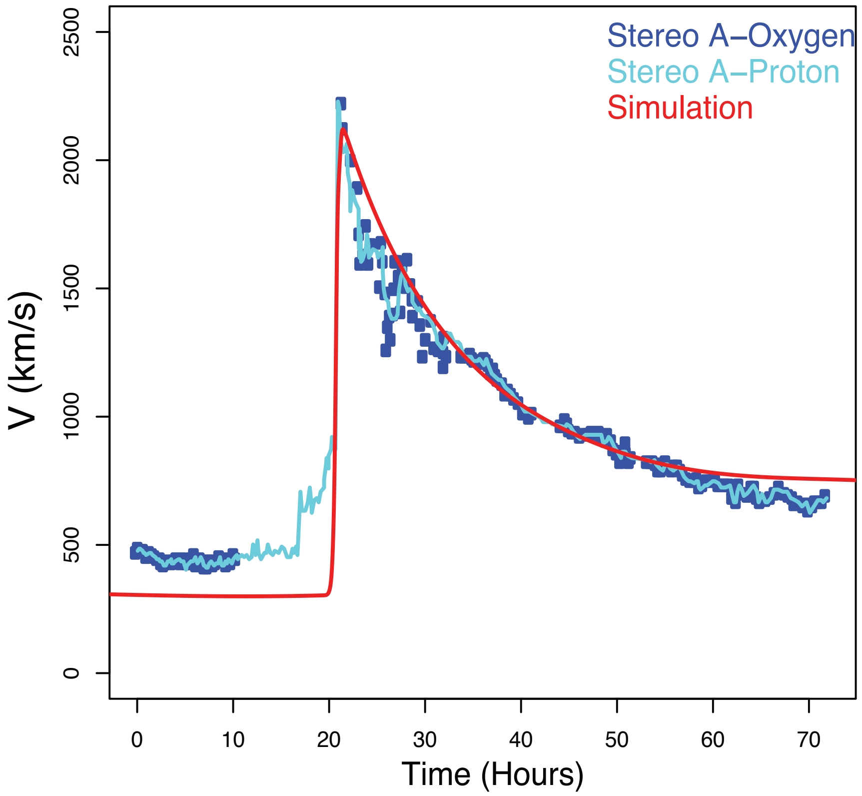
FLUX ROPE FITTING



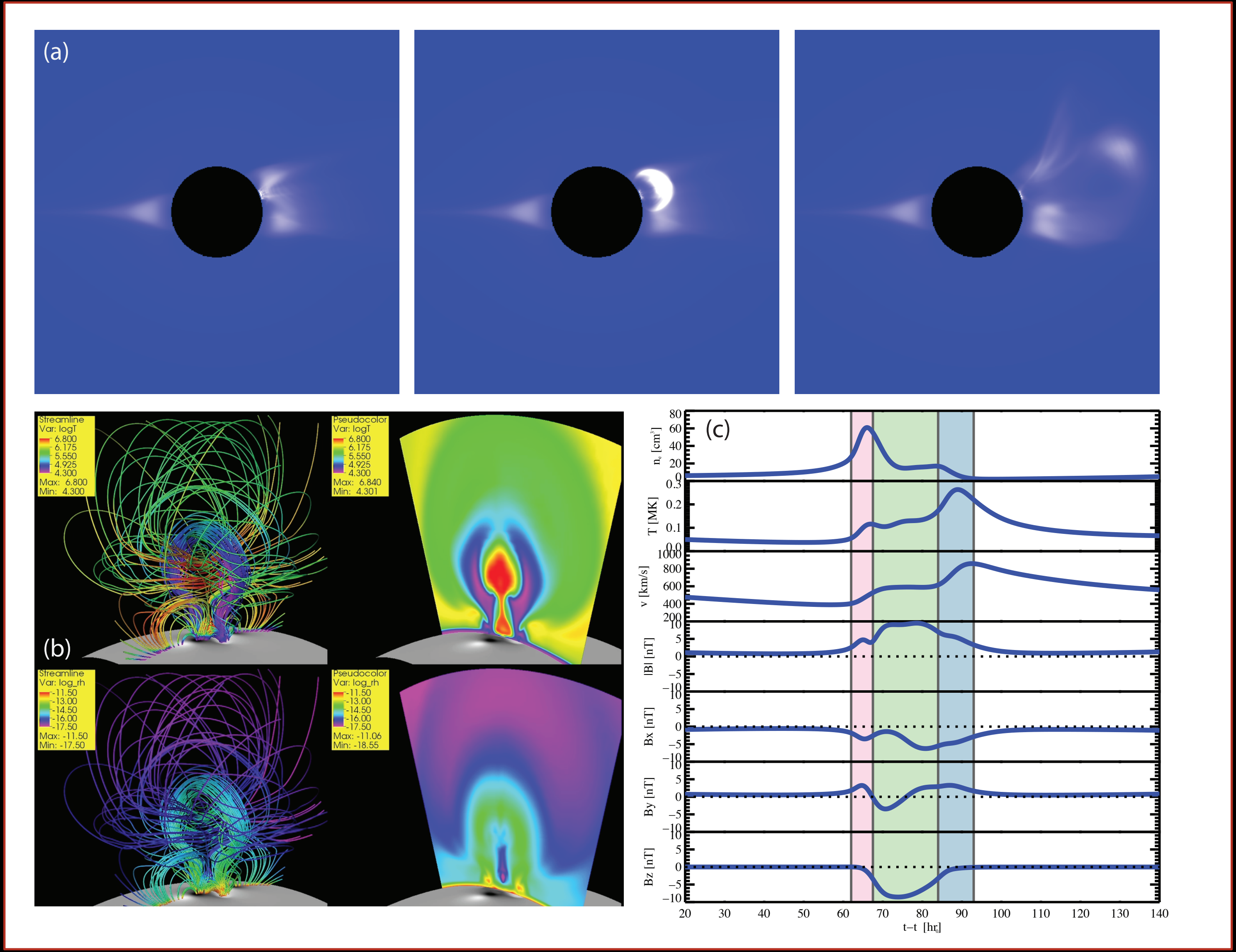
SIMPLE DYNAMIC MODELS OF ICMES



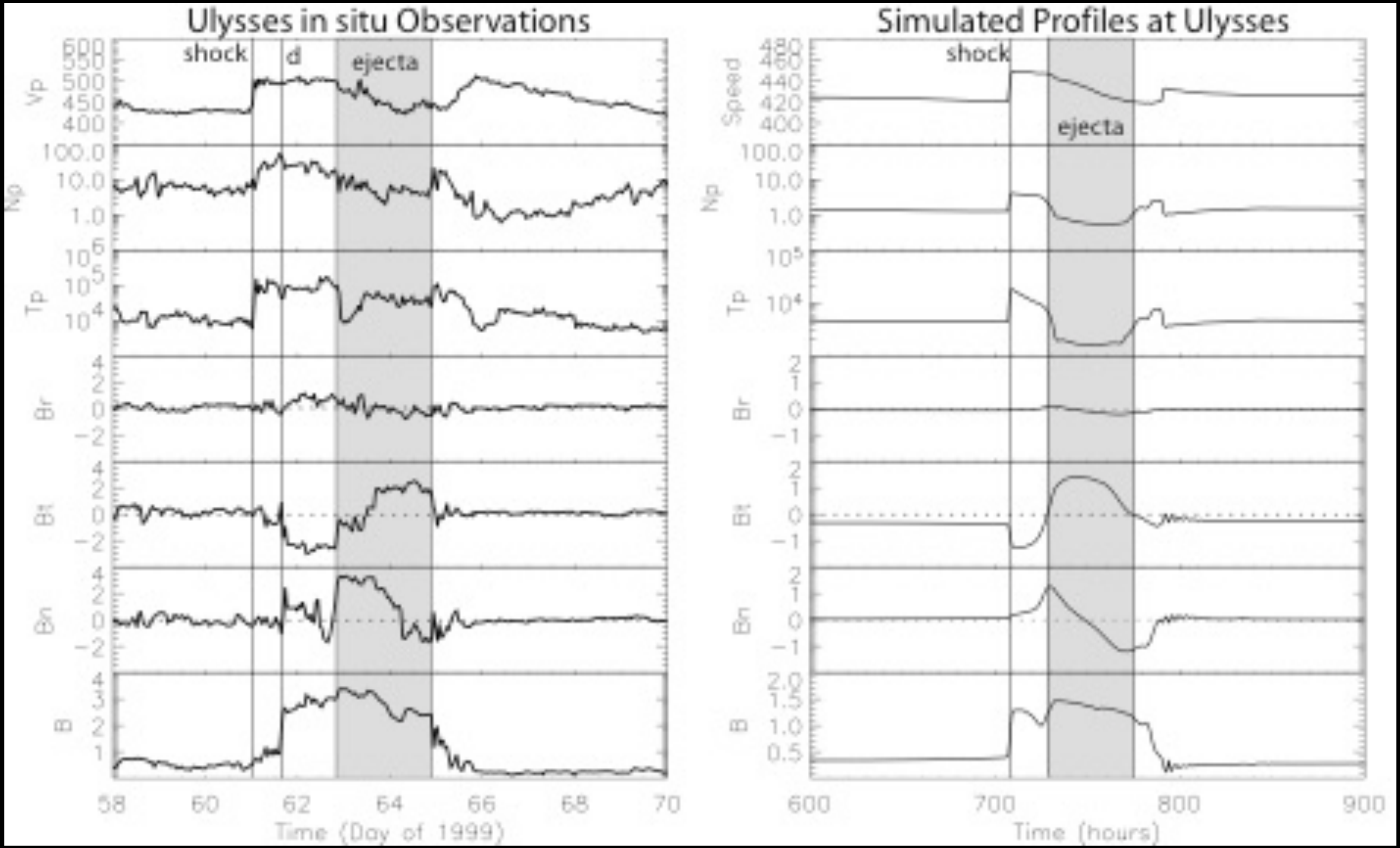




MORE SOPHISTICATED DYNAMIC FLUX ROPE MODELS



MODELLING IS NOT THE SAME AS PREDICTION: THE PITFALLS OF "SCIENTIFIC" COMPARISONS



SCIENTIFIC OBJECTIVES OF PROJECT ZED

1. Develop an easy-to-use framework for testing B_z prediction algorithms;
2. Develop a rigorous set of metrics with associated skill scores that include estimates of uncertainty;
3. Develop benchmark datasets (same data sources, sets, and sampling techniques);
4. Test the currently most promising statistical, analytical, and numerical modeling techniques;
5. Develop a prioritized set of new predictive techniques; and
6. Provide the completed framework as an open source resource to the scientific community.

WG2 AT THIS WORKSHOP (TUESDAY AM)

- **Coronal Mass Ejections: A Journey From Its Origin to Its Transport in the Interplanetary Medium** (Andrea Borgazzi, Invited)
- **Balance of Energy in a CME** (Héctor J. Durand Manterola)
- **Plasma Interaction Processes That Lead to Viscous Forces in the Solar Wind** (Héctor Pérez de Tejada)
- **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)
- **Dynamics of Coronal Mass Ejections in the Interplanetary Medium in Two Dimensions** (Juan Carlos González Marin)
- **Study of the Transport of Heat in the Solar Corona** (Diana Gamborino Uzcanga*, J. Martinell Benito, D. del Castillo Negrete)