3D evolution of flux-rope CMEs from the Sun to 1 AU

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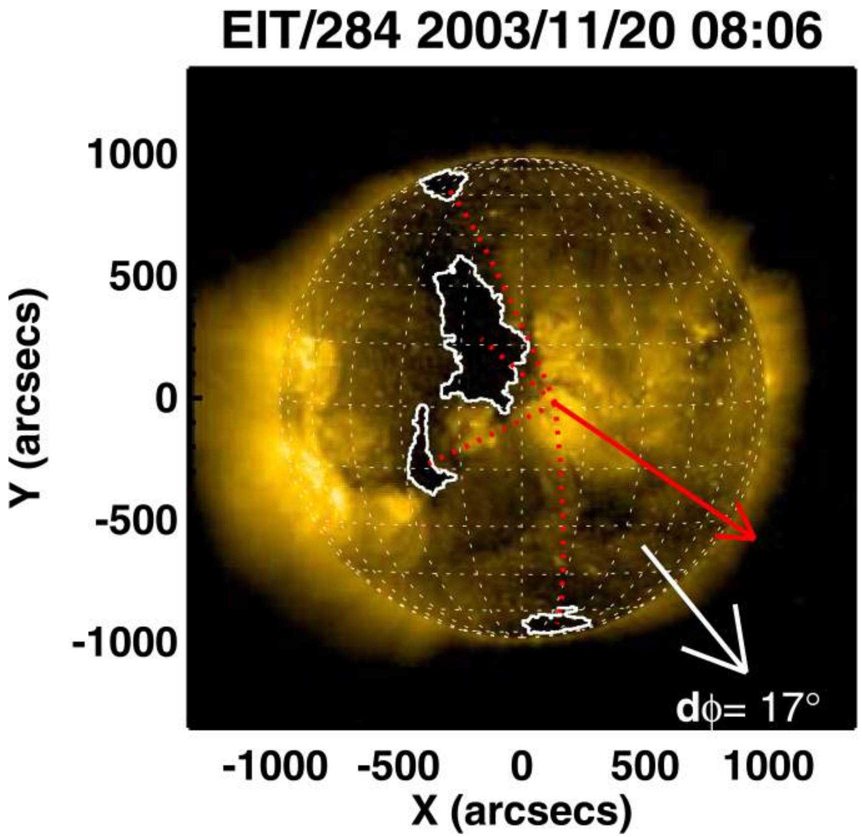
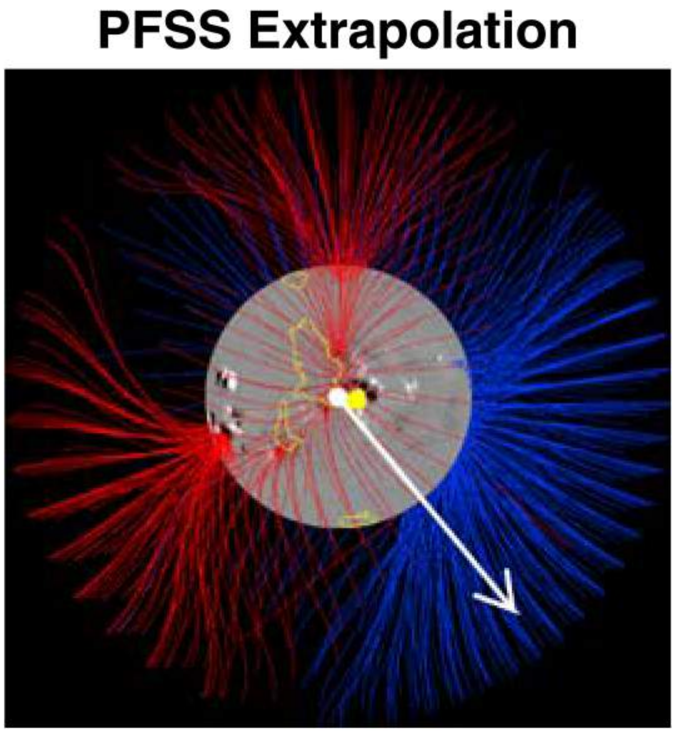
Outline

- Motivation: background and importance for space weather
- 3D evolution: components and assumptions
- Analysis: techniques and their combination
- Evolution of average-speed CMEs
- Evolution of slow and fast CMEs
- Potential errors and future prospectives

Motivation

Deflections can cause central (limb) CMEs to miss (hit) the Earth.

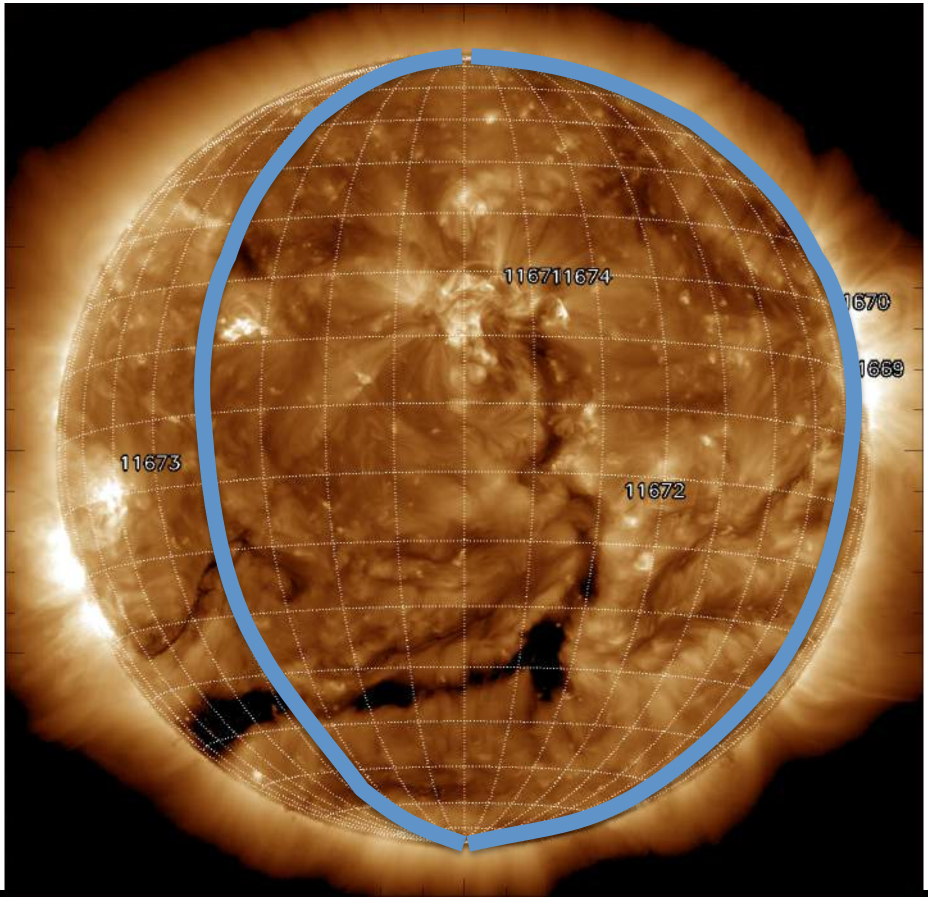




Gopalswamy *et al.*, 2009

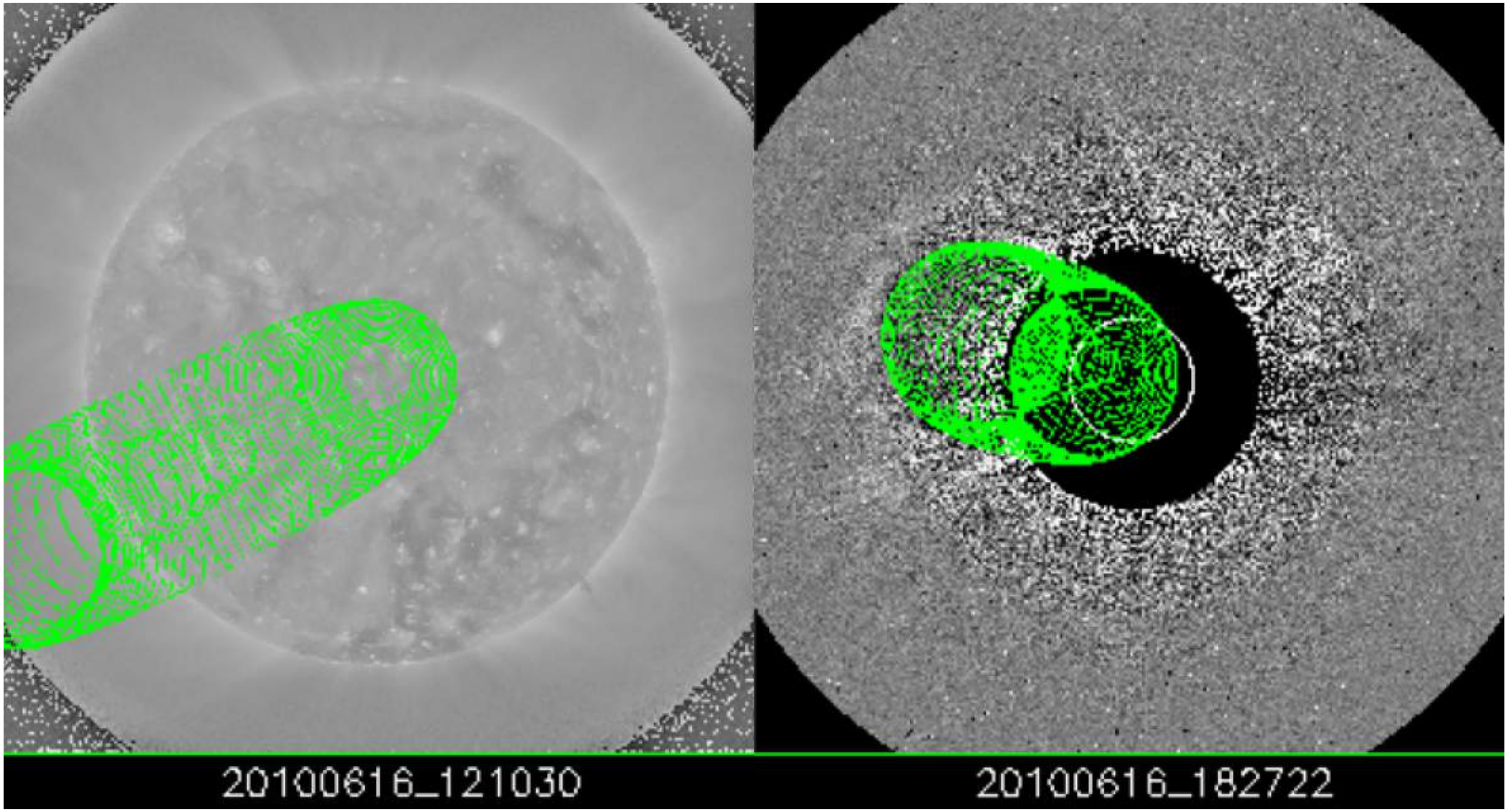
Motivation

The solar source distribution of geoeffective CMEs has <u>East-West assymetry</u> (E40-W75) ➔ statistical proof of longitudinal deflection and a hint about its dependence on Parker spiral Wang et al., 2002



Motivation

Rotations can change B_Z at 1 AU.



Vourlidas *et al.*, 2011

3D evolution of CMEs

Components of 3D evolution:

- Longitudinal and latitudinal deflections
- Rotation
- Expansion
- Acceleration/deceleration
- Front flattening
- «Pancaking» due to radial expansion
- Skewing due to solar rotation
- Local deformations due to differential structure of ambient solar wind

3D evolution of CMEs: zero approximation

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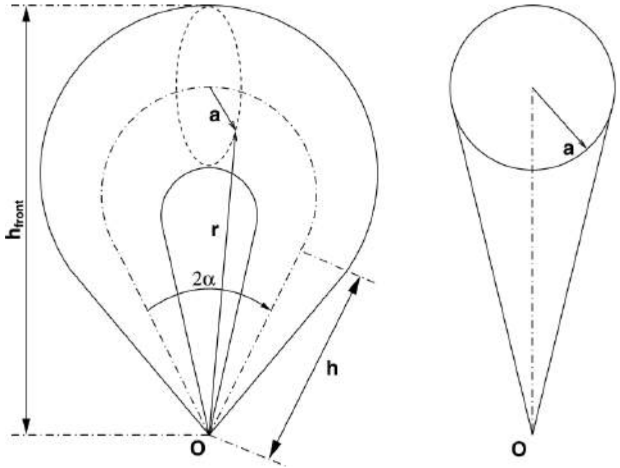
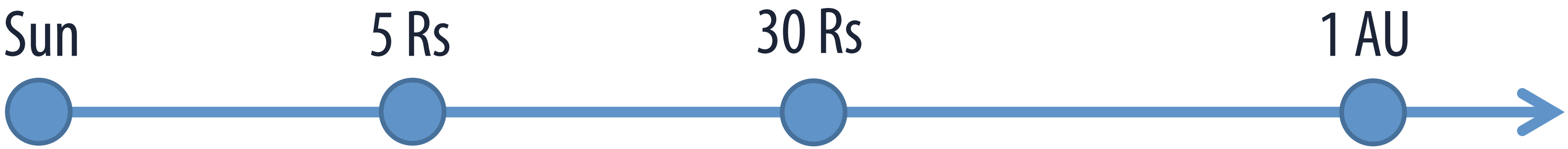
Assumptions

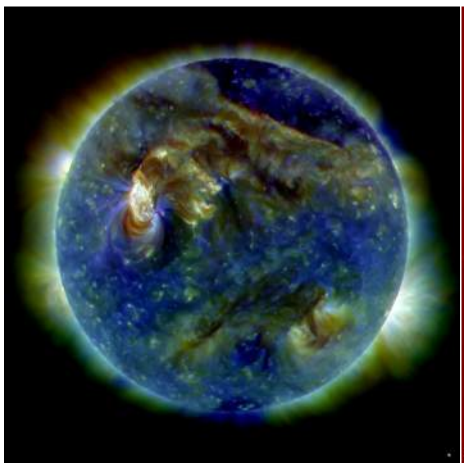
- CME has a flux rope inside (FR-CME)
- FR-CME geometry is described by GCS model

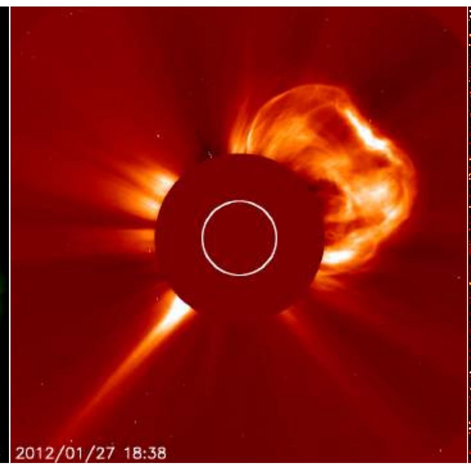


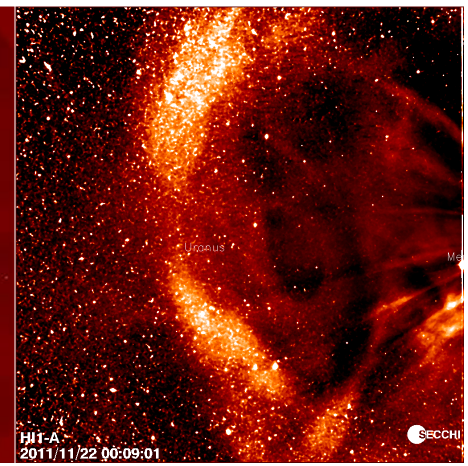
Thernisien *et al.*, 2009

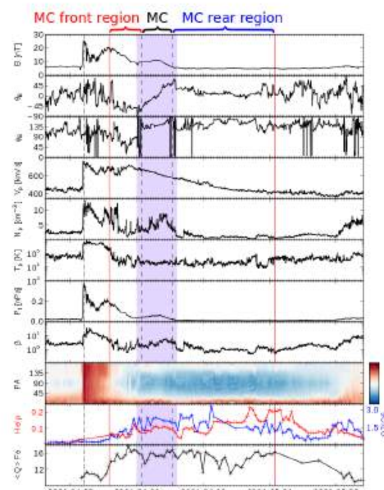
Combining various observations











Kilpua *et al.*, 2014

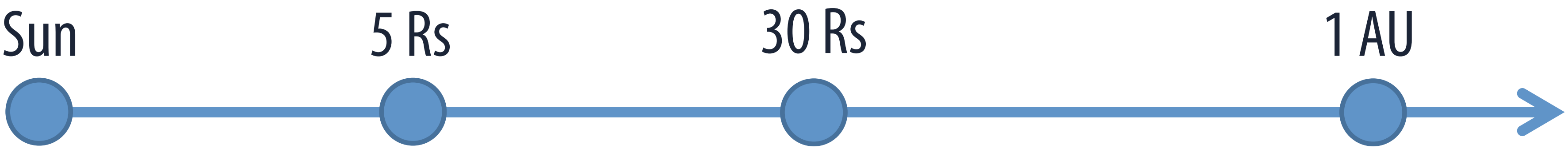
EUV observations

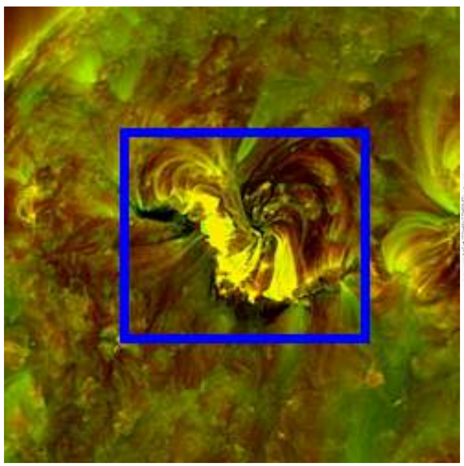
coronagraph observations

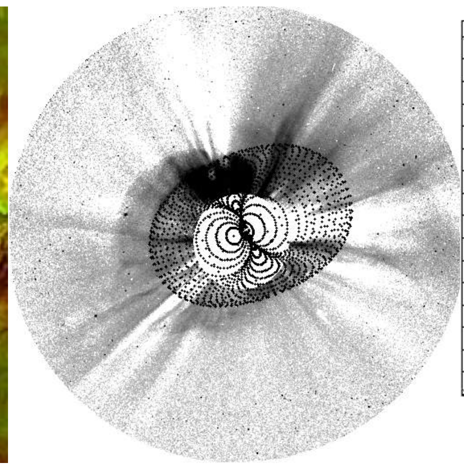
heliospheric imaging

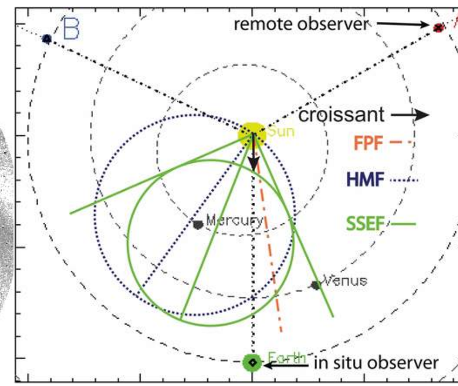
in-situ observations

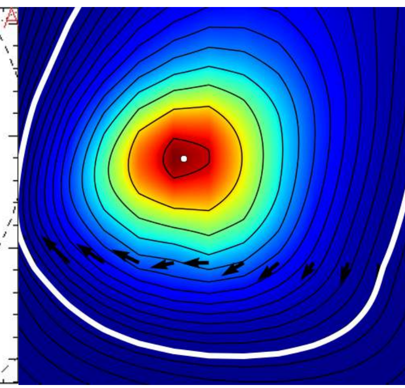
Combining various techniques











Möstl *et al.*, 2014

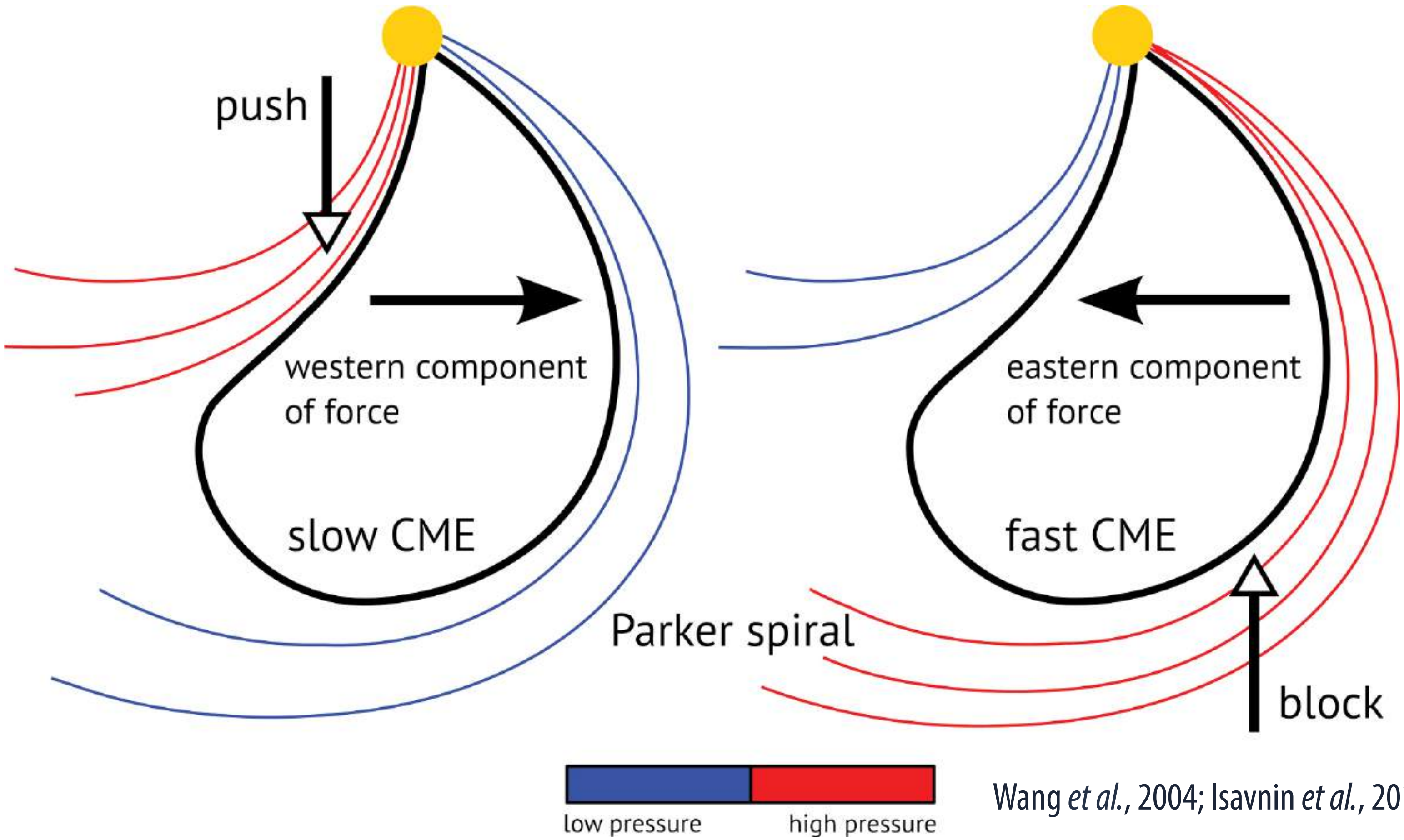
CME source & post-eruptive arcades
➔ direction & orientation

FM ➔ direction & orientation

Fixed-Φ, HM or SSE
➔ only direction

GSR or other FR fitting models
➔ only local orientation

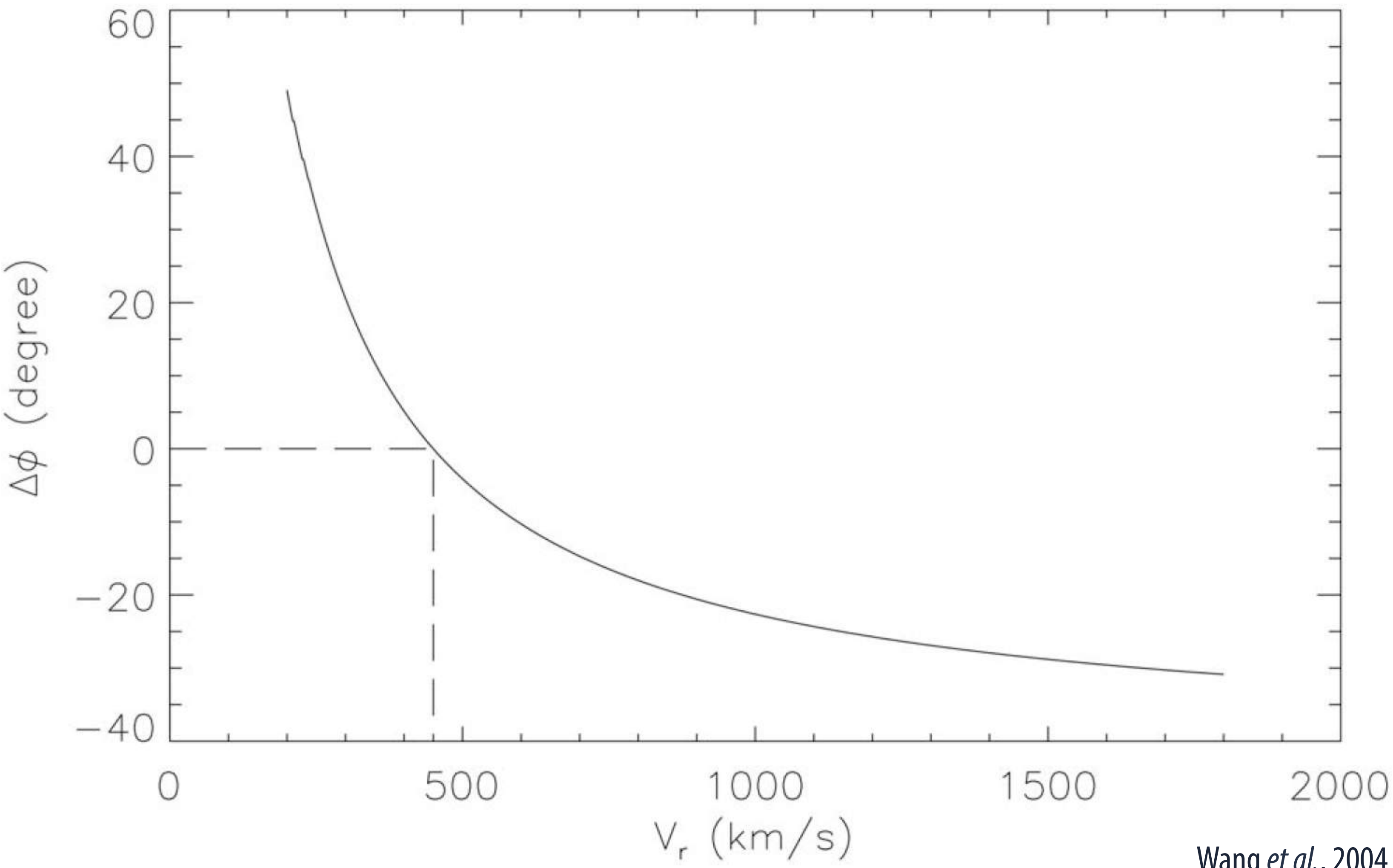
Deflections: kinematic description



Wang *et al.*, 2004; Isavnin *et al.*, 2013

Magnetic interaction with the Parker-spiral-structured solar wind

Deflections: kinematic description

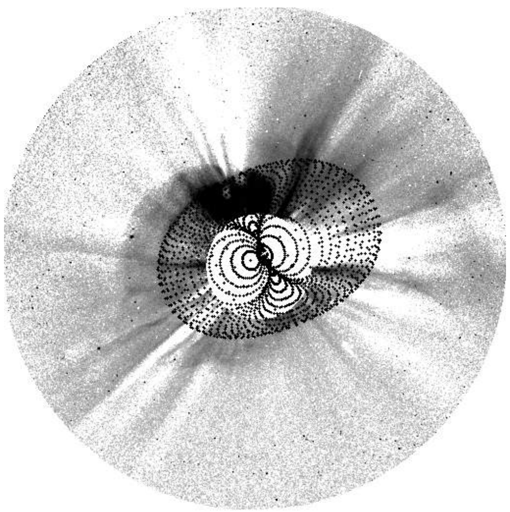


Wang *et al.*, 2004

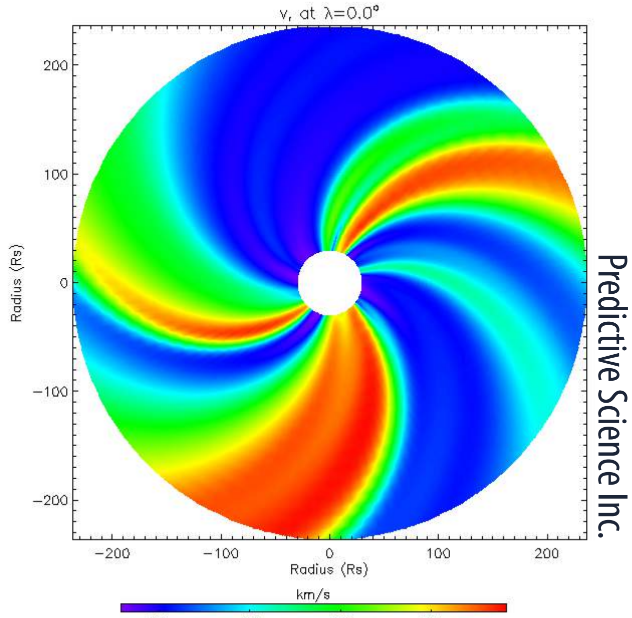
Combining various techniques

30 Rs

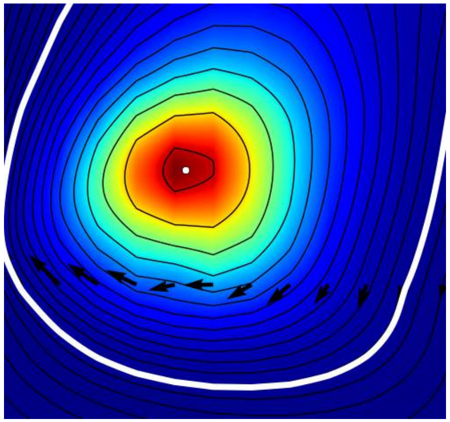
1 AU



last orientation from FM

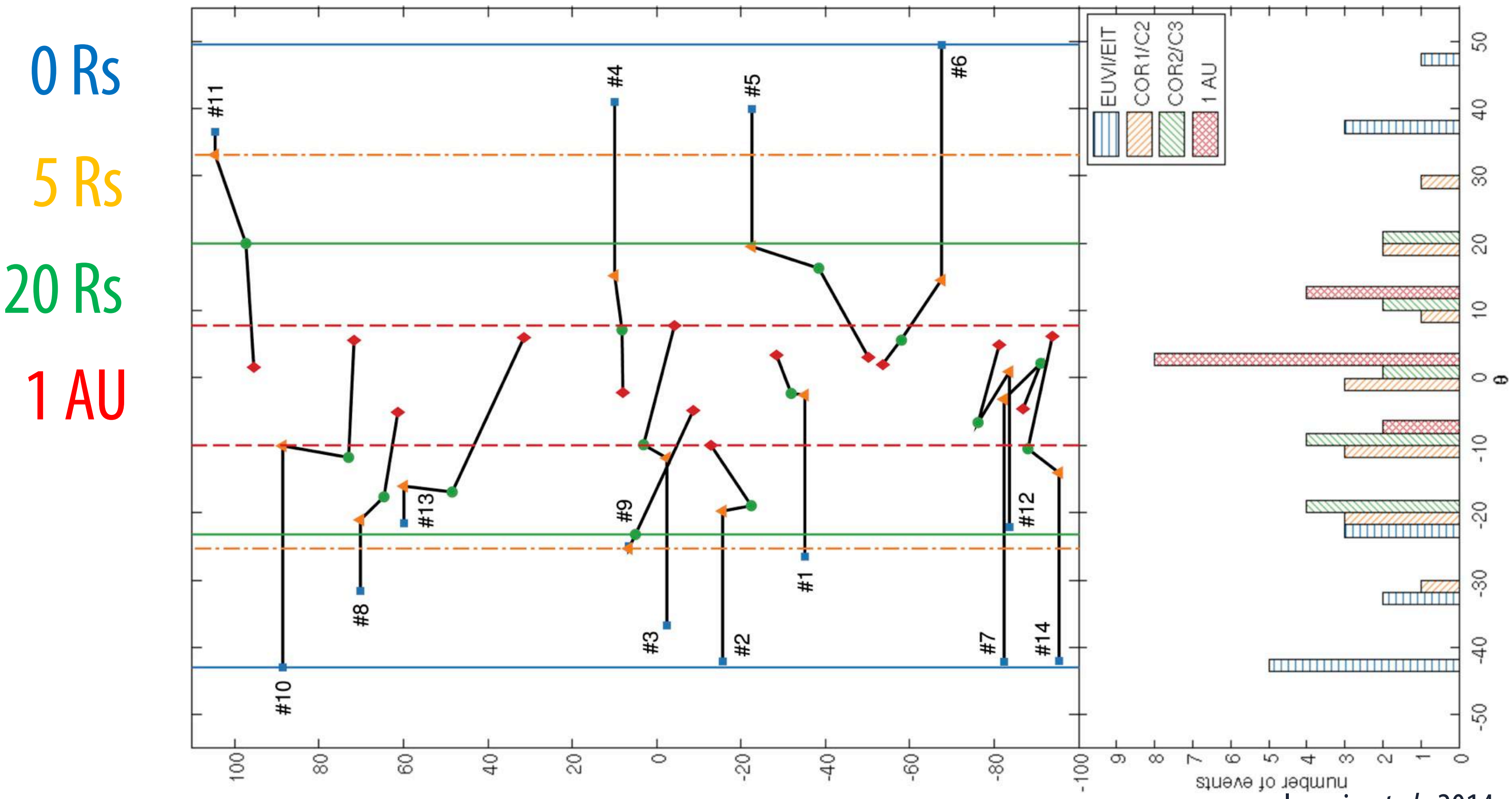


MHD-simulated background solar wind (MAS model)



local orientation as a constraint for global orientation

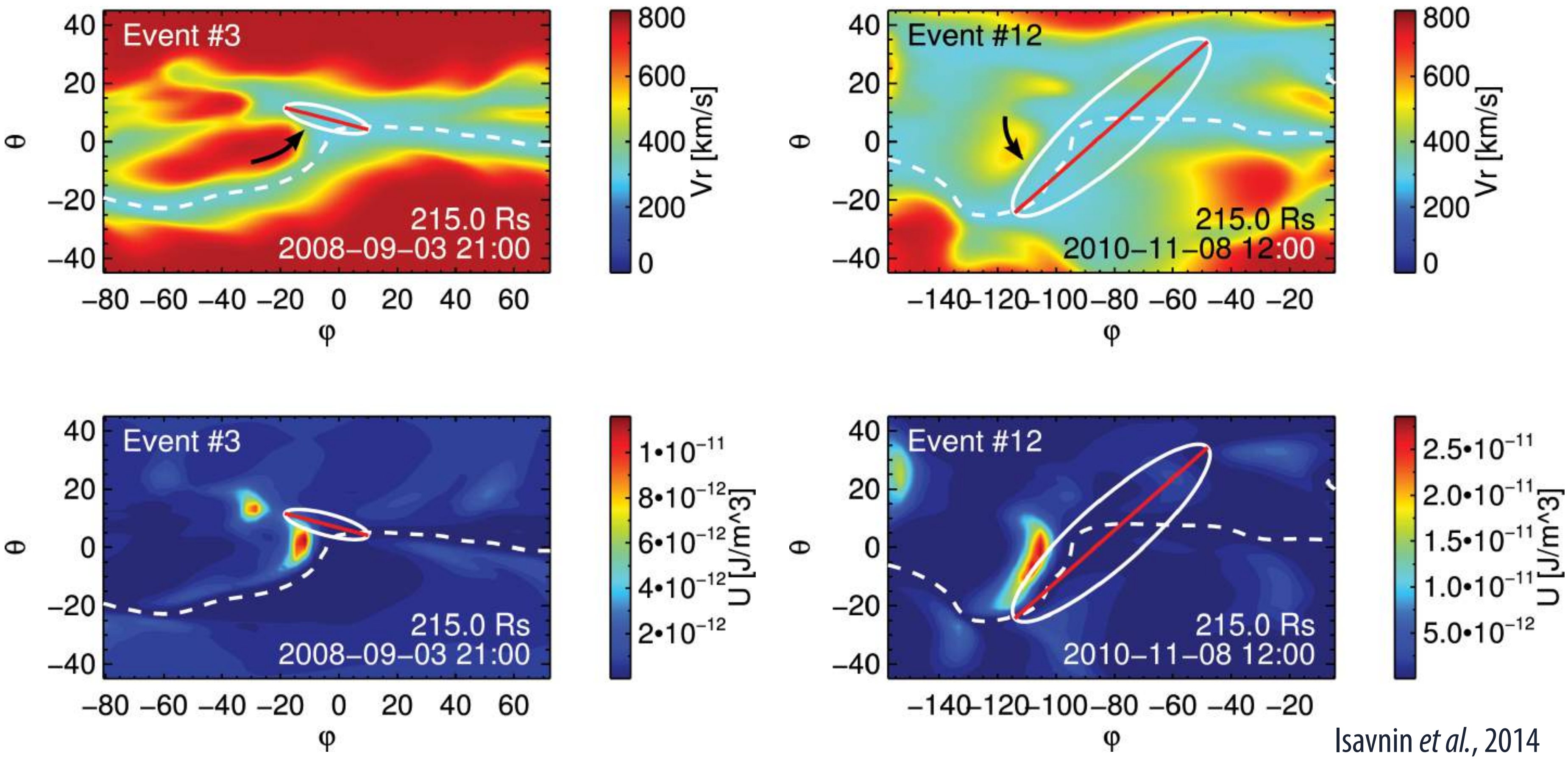
Deflections toward equatorial plane



Isavnin *et al.*, 2014

Flux rope global axis direction during its travel from the Sun to 1 AU

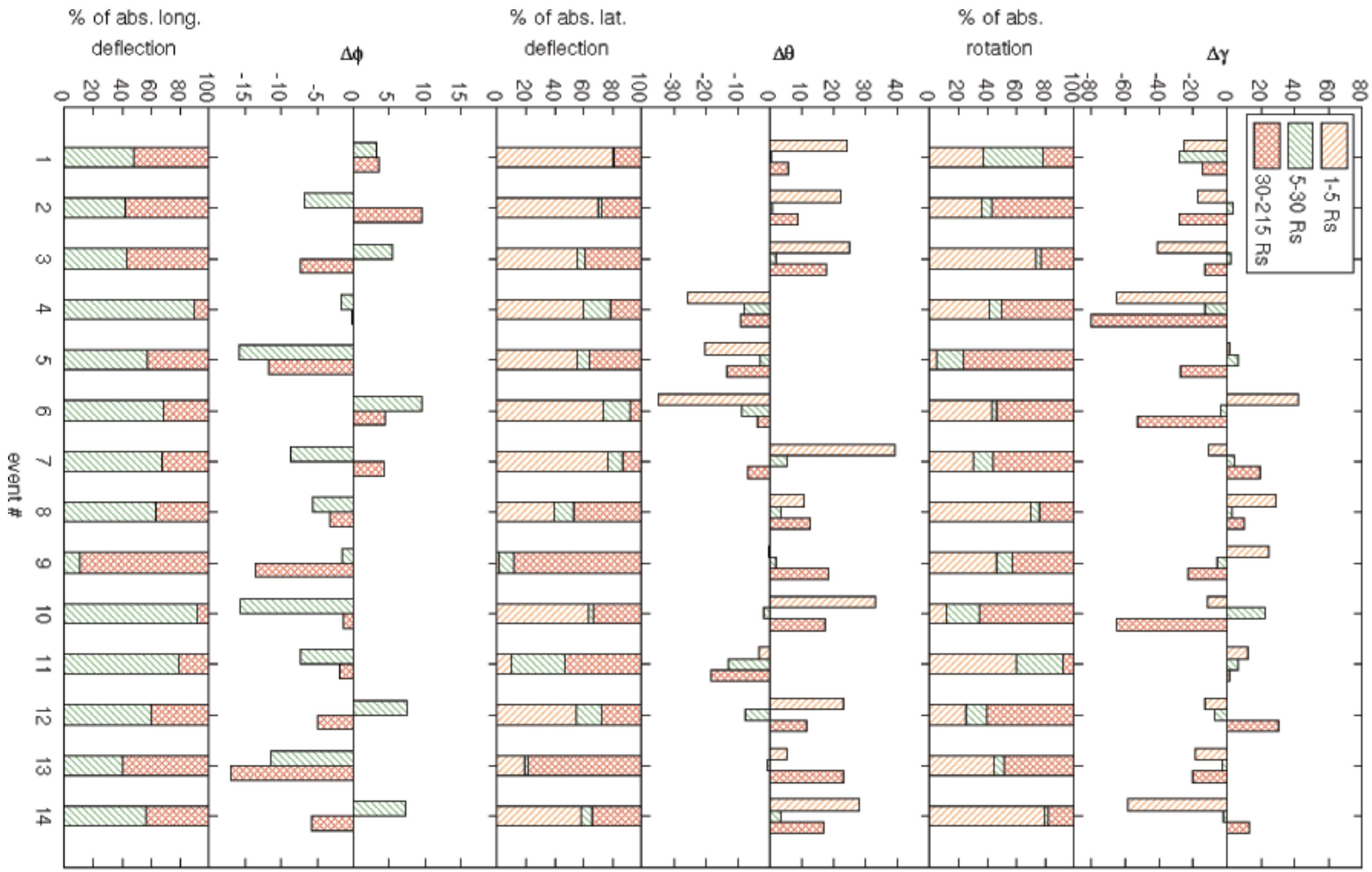
Rotation relative to HCS



Isavnin *et al.*, 2014

Flux rope orientation superimposed on velocity (top) and magnetic energy density (bottom) maps at 1 AU for two events

Deflections and rotations



Isavnin *et al.*, 2014

Deflections and rotations

- Flux ropes continuously deflect towards the solar equatorial plane during their travel from the Sun to 1 AU.
- Flux ropes rotate while getting approximately aligned with heliospheric current sheet.
- 60% of flux evolution happens during the first 14% of their travel distance from the Sun to 1 AU.
- The studied events are planned to be used in VarSITI project for evaluation of CME propagation simulations.

…average-speed CMEs. And what about very slow and very fast ones?

Evolution of slow and fast CMEs

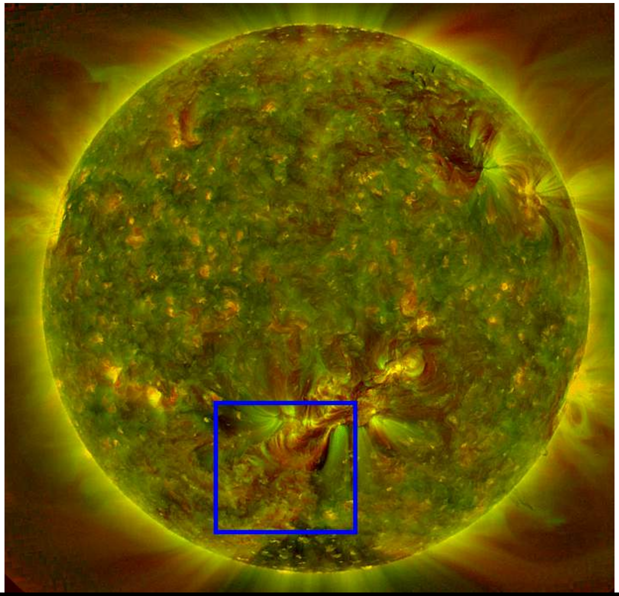
Slow

28 February 2010

V_r = 300 km/s in the lower corona

a = 5.9 m/s^2 at 20 R_S

V_r = 355 km/s at 1 AU



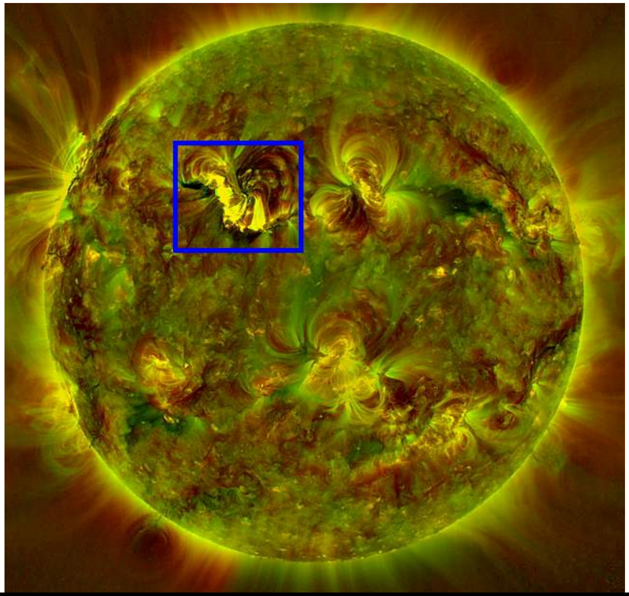
Fast

1 October 2011

V_r = 1238 km/s in the lower corona

a = –10.1 m/s^2 at 20 R_S

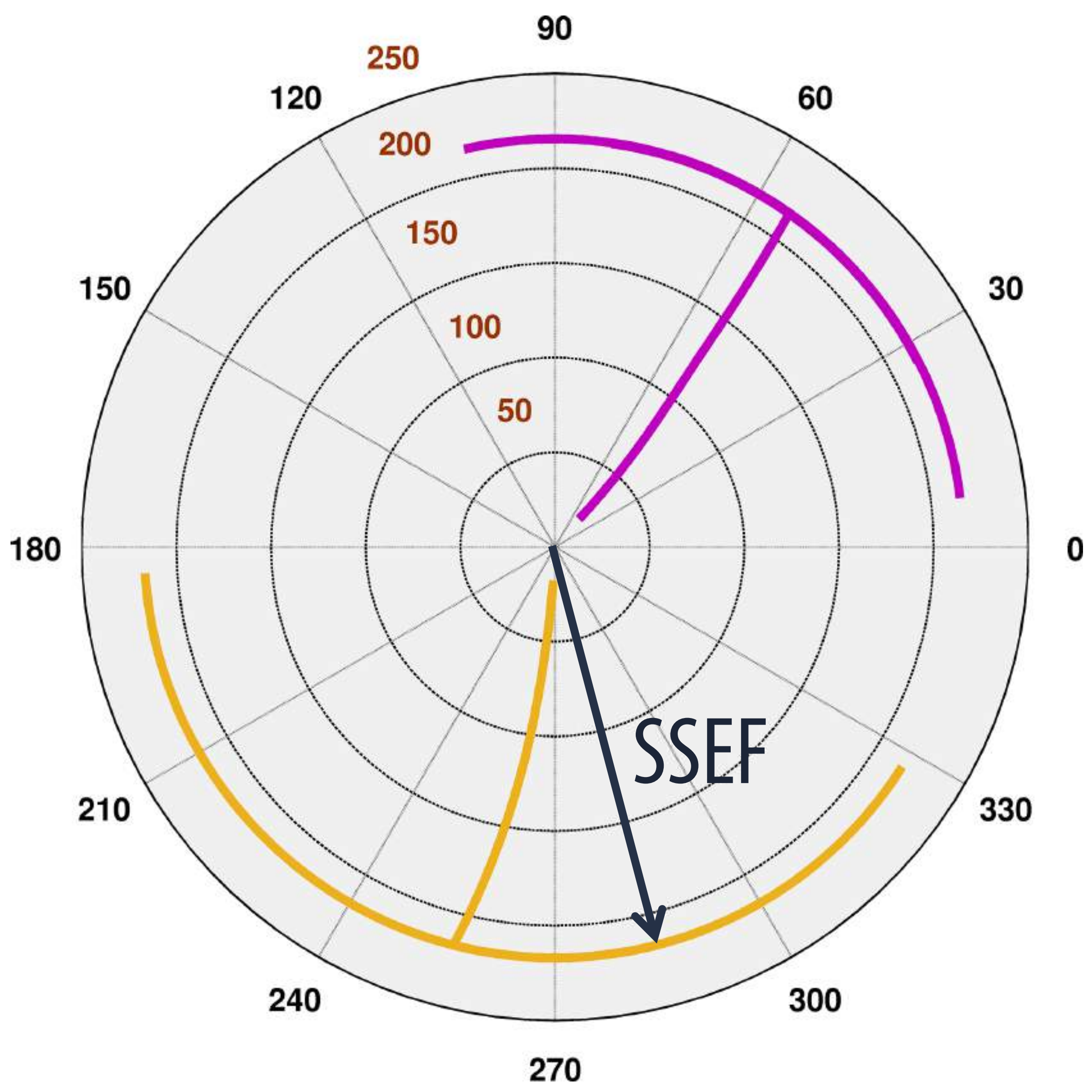
V_r = 683 km/s at 1 AU



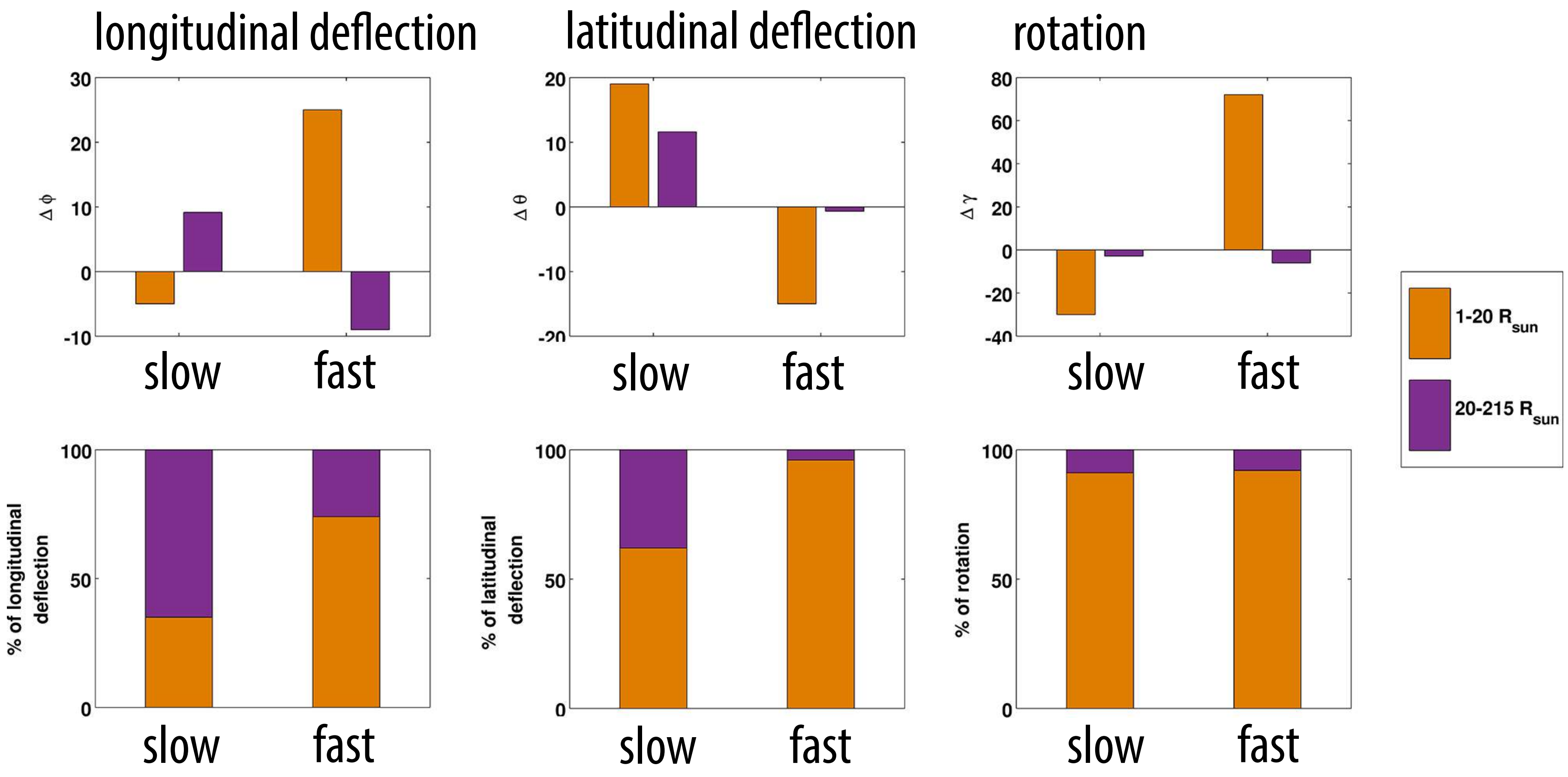
Longitudinal deflection

slow

fast



Deflections and rotations



Deflections and rotations

- The fast CME experienced most of deflection (75% longitudinal, 94% latitudinal) in the lower corona.
- Both fast and slow CMEs experienced the majority of rotation (92%) in the lower corona and got approximately aligned with HCS.

Potential errors

- Not all evolution components are treated: too simple model
- High-pressure interaction regions between GCS-modelled structure and ambient solar wind are treated as solid walls
- Separate model for magnetic field: combination of different models sums the errors
- Other analysis errors: non-polarized images, fitting errors, *etc.*

But it is possible to eliminate or reduce most of the errors!

A way to go

- Fully 3D FR model with magnetic field included, capable of most global FR deformations
- Same model to be fitted to all observations: less assumptions, more consistency
- Forecasting capability

. . . a work in progress