

# Variation in CME Deflection and Rotation over the Solar Cycle



Christina Kay  
NPP Fellow  
NASA GSFC/USRA  
[christina.d.kay@nasa.gov](mailto:christina.d.kay@nasa.gov)

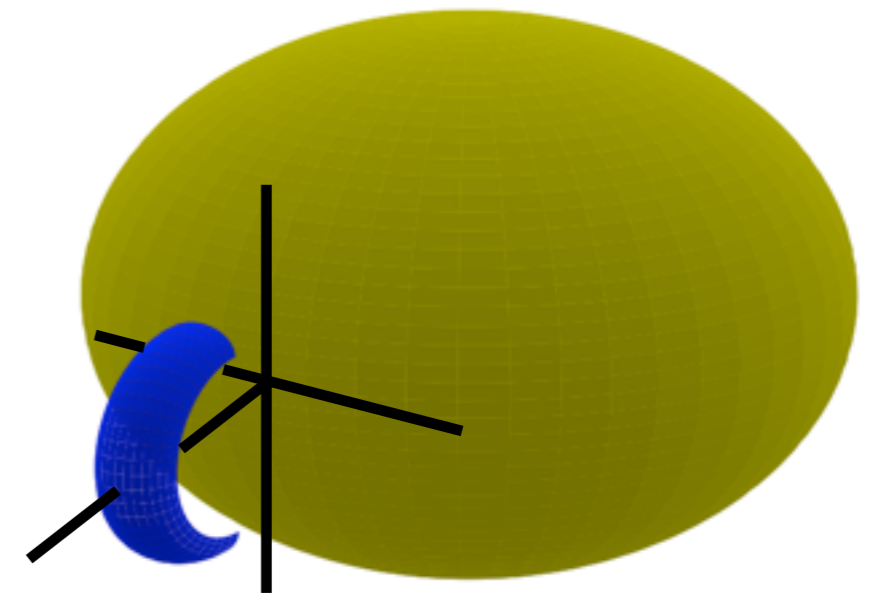
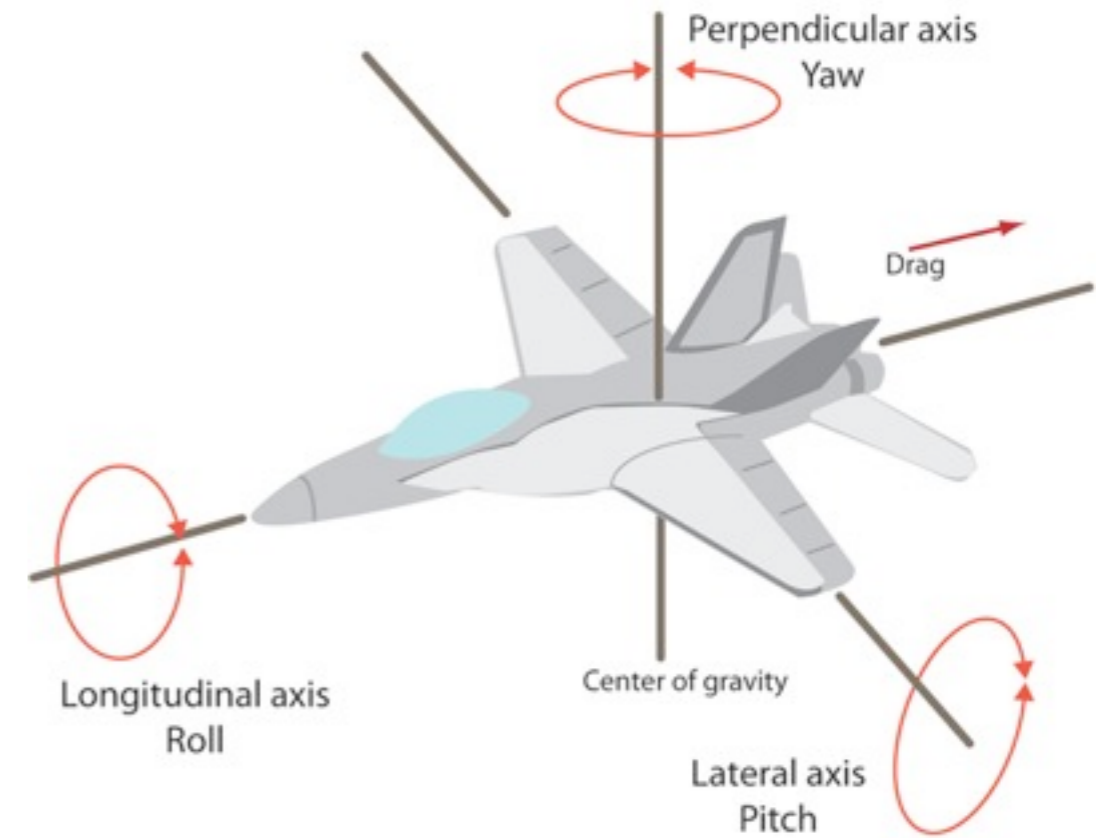
collaborators: N. Gopalswamy (NASA GSFC), M. Opher (Boston Univ.)

# Historical Perspective

- Skylab observations suggested deflection towards equator (Hildner 1977) but trend less obvious in Solar Maximum Mission observations (MacQueen+ 1986)
- STEREO observations show both latitudinal and longitudinal deflections (e.g. Byrne+ 2010, Liu+ 2010, Isavnin+ 2014)
- CMEs deflect toward the Heliospheric Current Sheet and away from coronal holes (e.g. Cremades & Bothmer 2004, Kilpua+ 2009, Gopalswamy+ 2009)
- Direction of deflection typically same as direction of magnetic gradients (Shen+ 2011, Gui+ 2011)
- Direction and magnitude of deflections should vary as the solar magnetic field varies over the solar cycle

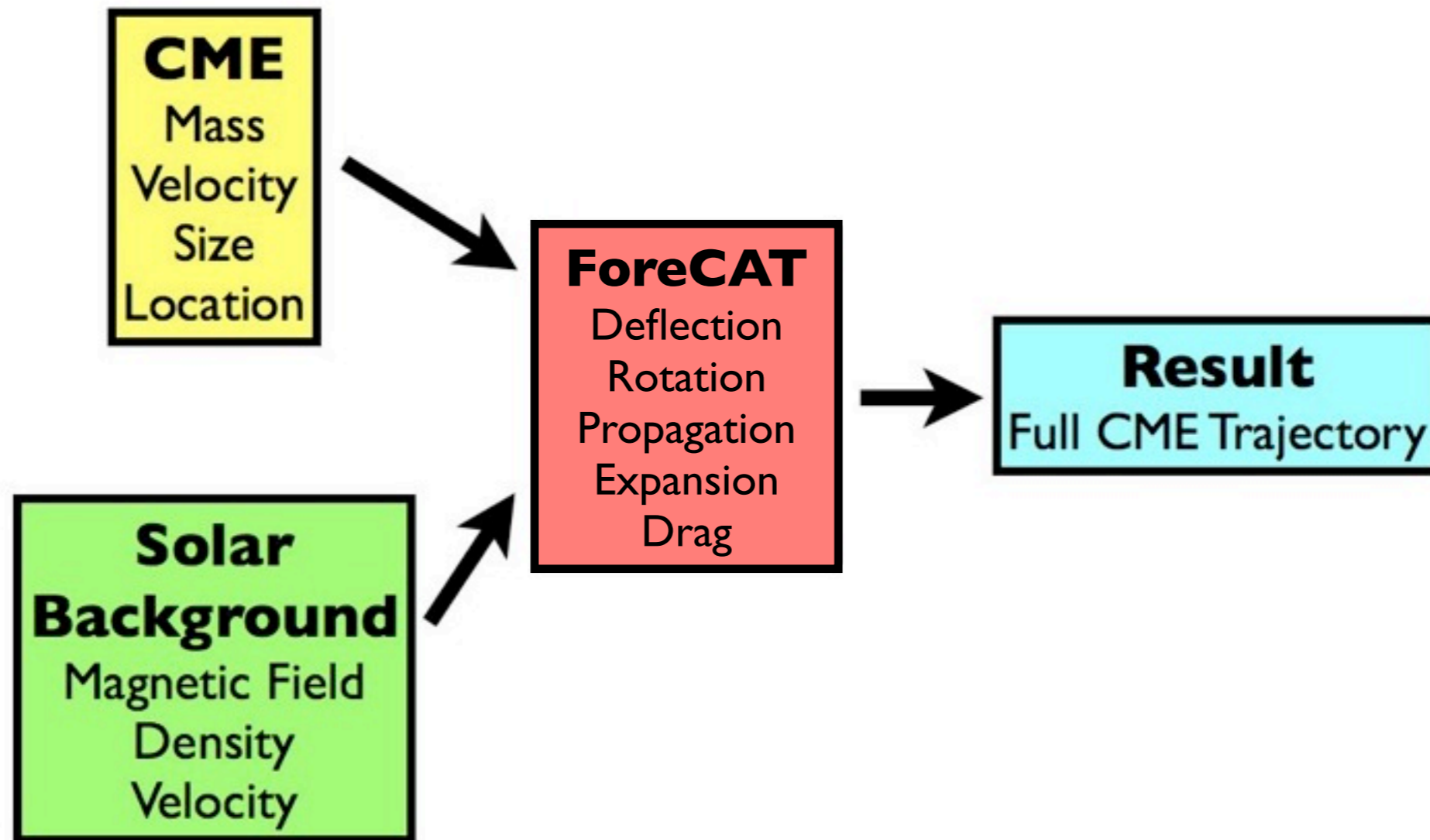
# Deflection and Rotation

- Lack of precise definitions/consistency
- Analogous to pitch, yaw, and roll
  - Rotation = roll
  - Deflection  $\approx$  yaw + pitch
- Measure deflection with respect to Sun-centered coordinates, motion occurs with respect to location of footpoints



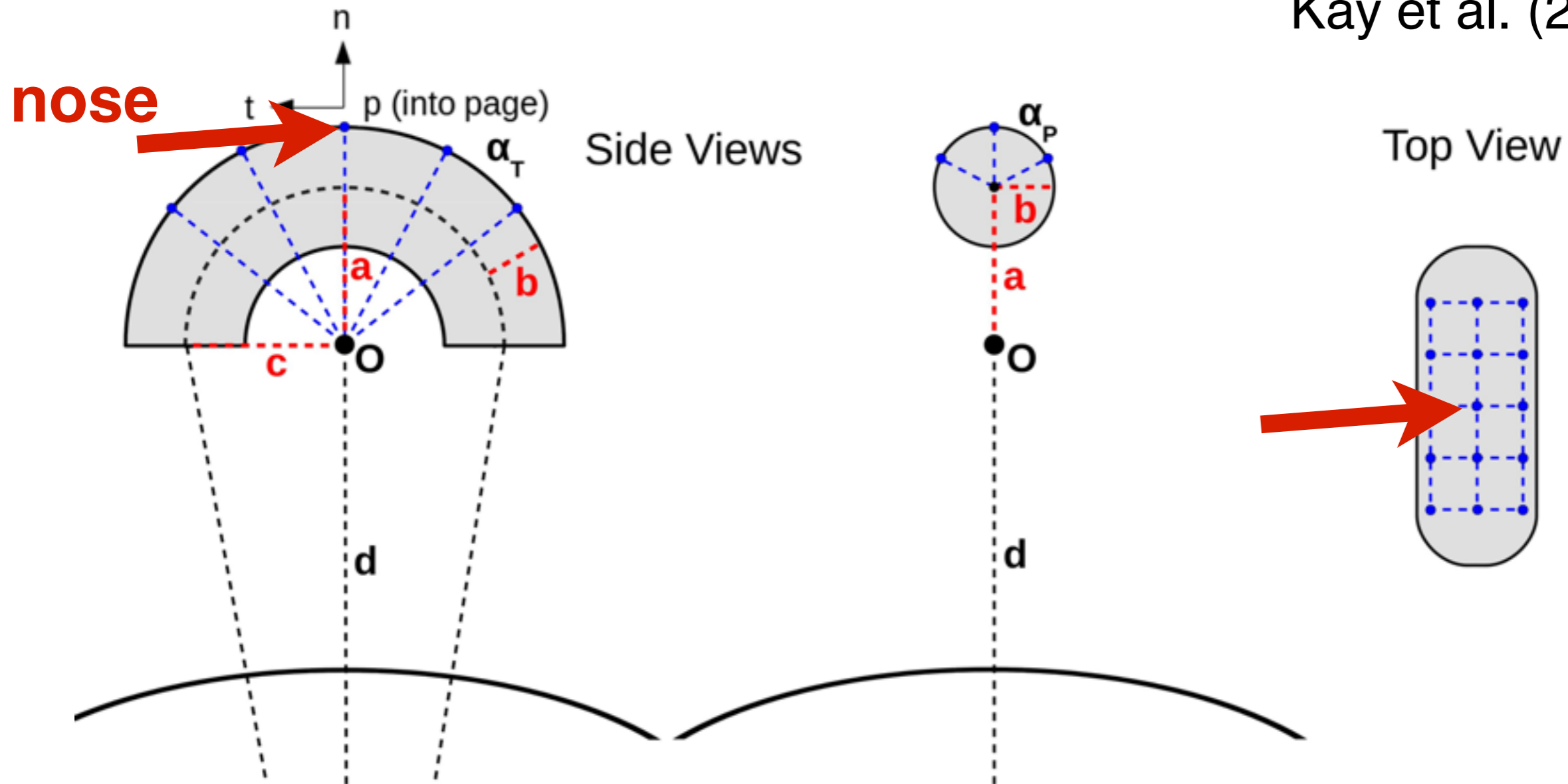
# Forecasting a CME's Altered Trajectory

Kay et al. (2013, 2015)



# ForeCAT CME

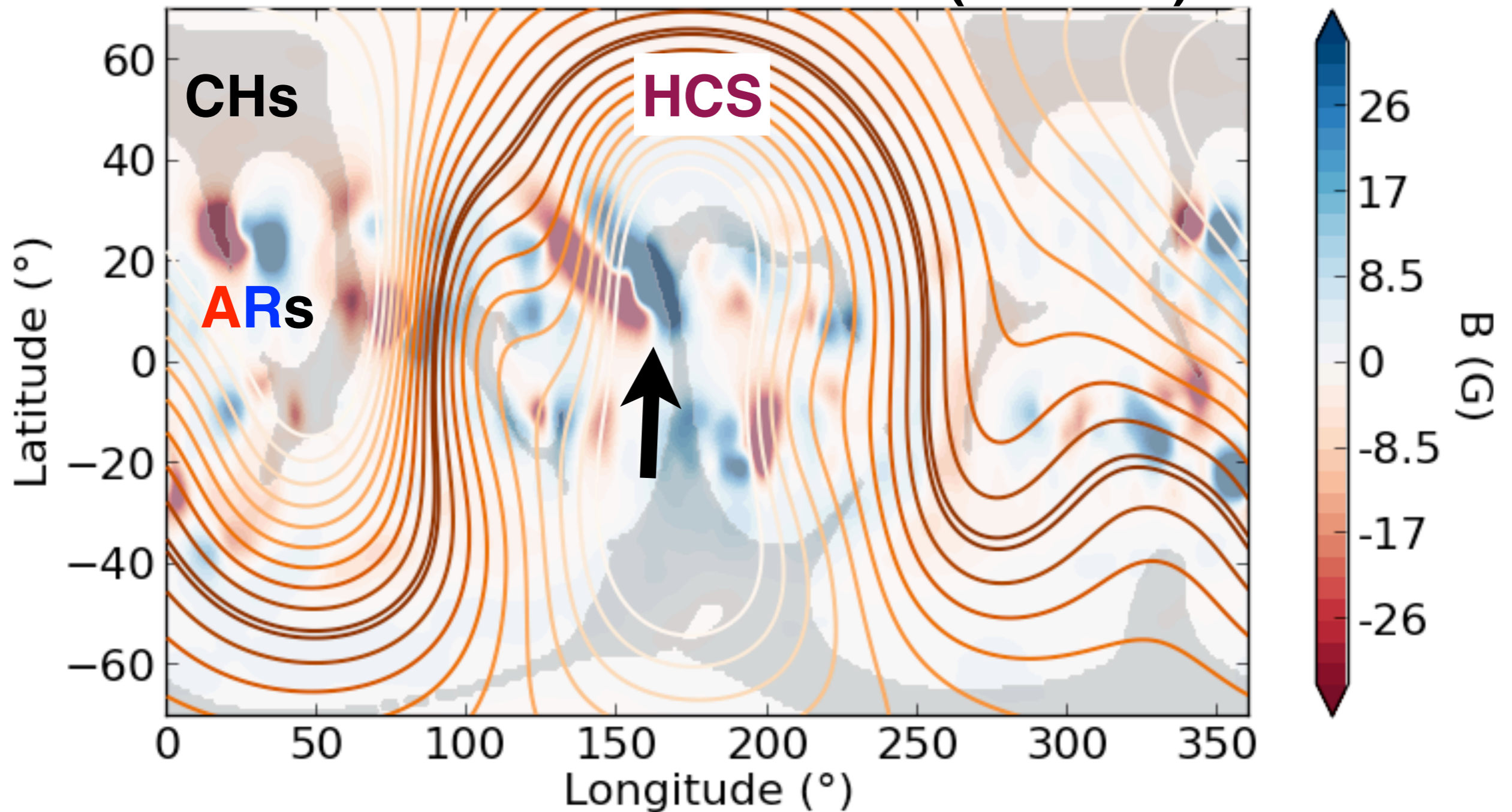
Kay et al. (2015)



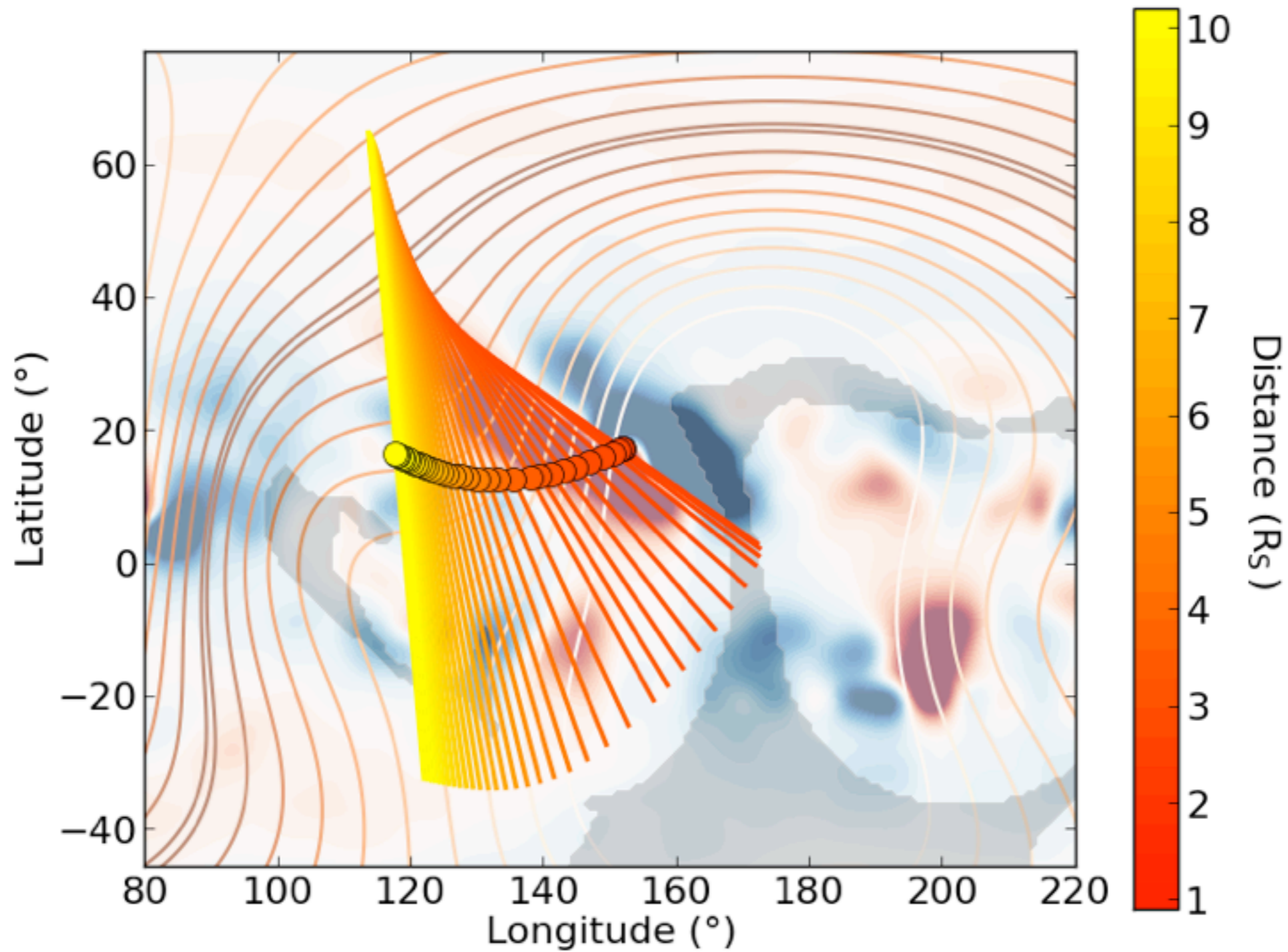
- Describe CME flux rope with torus
  - Currently do not include any deformation of shape

# Magnetic Background

CR 1975 Max of SC 23 (04/2001)

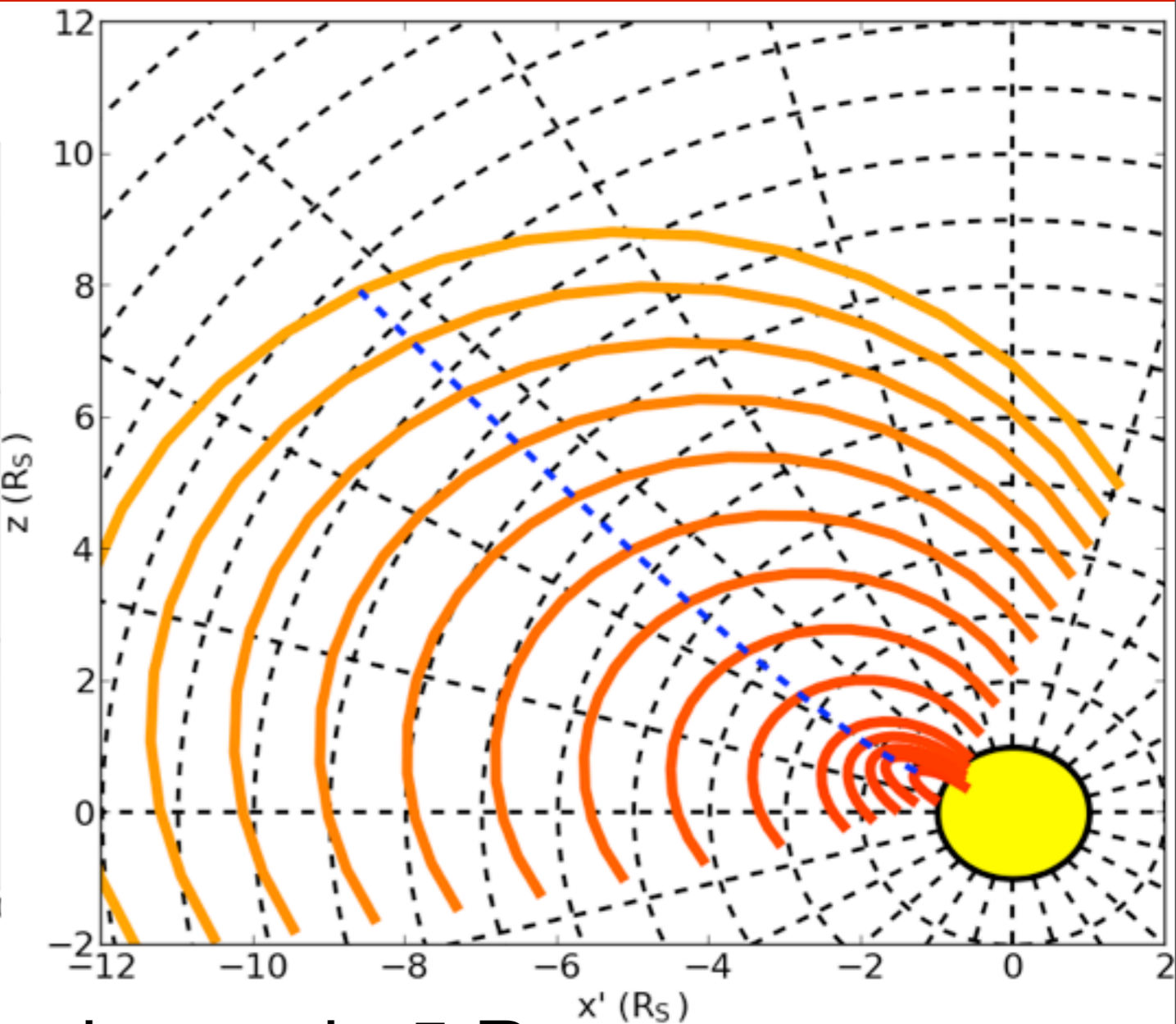
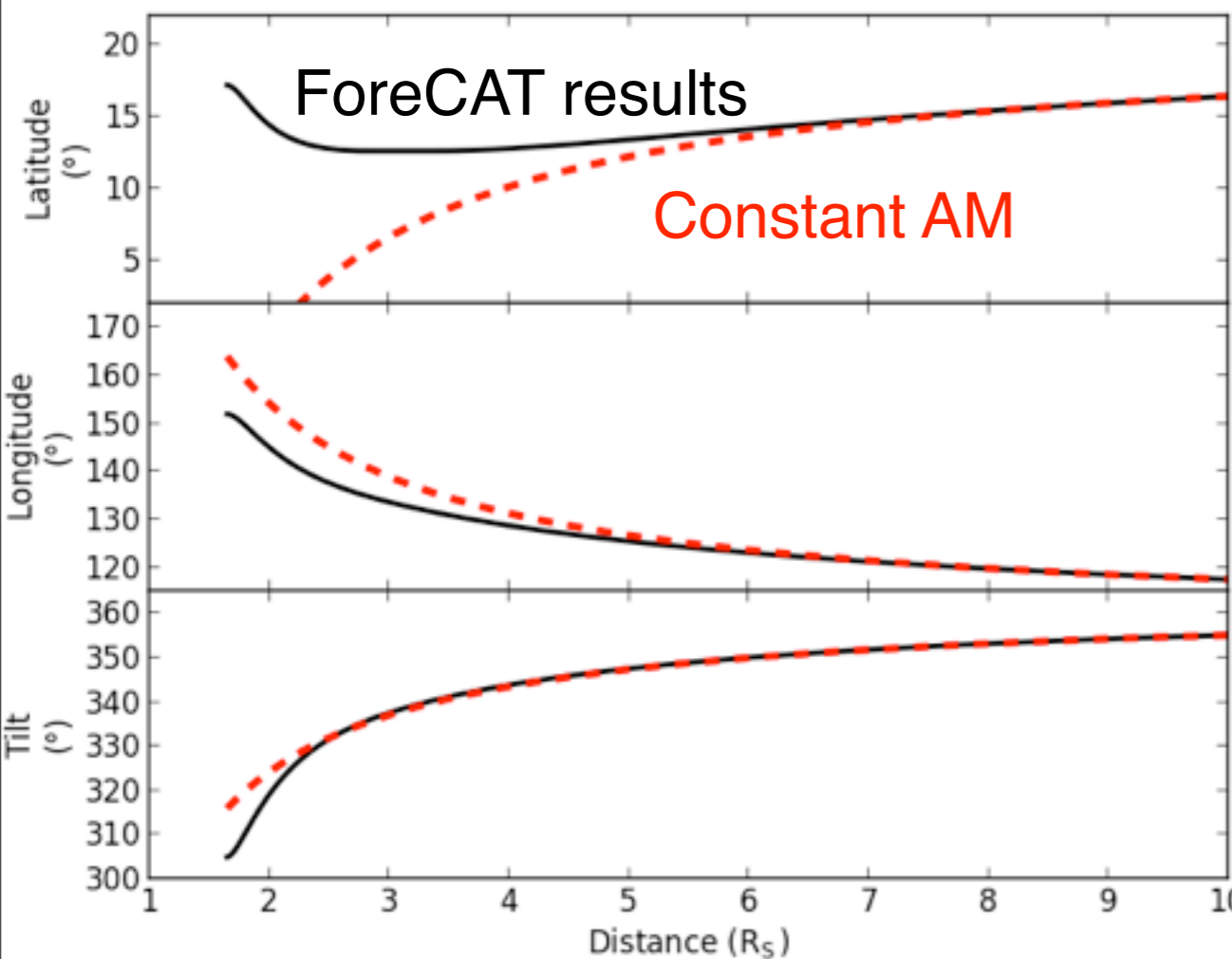


# Single CME



# Angular Momentum

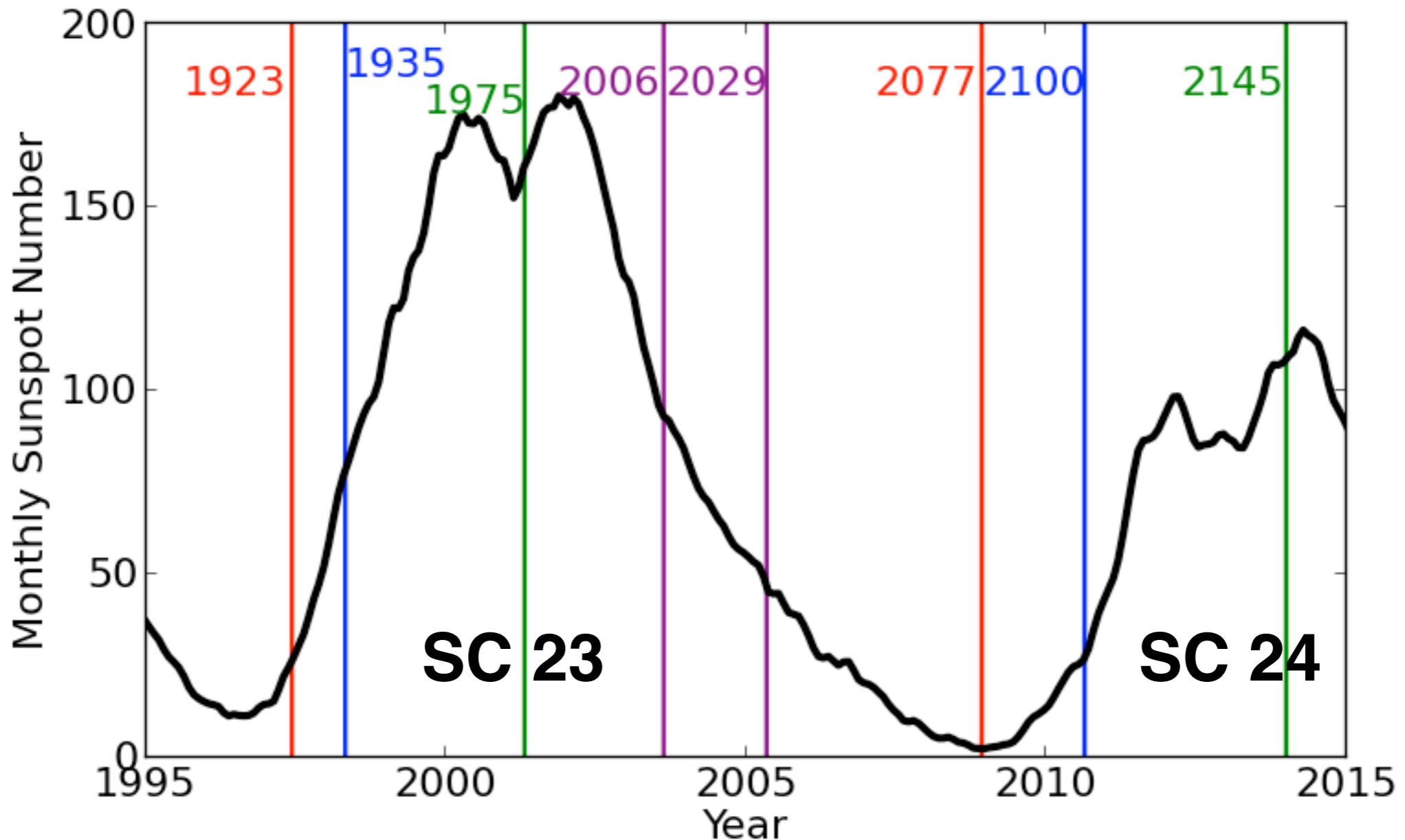
Kay et al. (2015b)



- Constant angular momentum beyond  $\sim 5 R_S$ 
  - CME moves in straight line but lat/lon can still change
- Coronagraph obs. from single viewpoint can be confusing

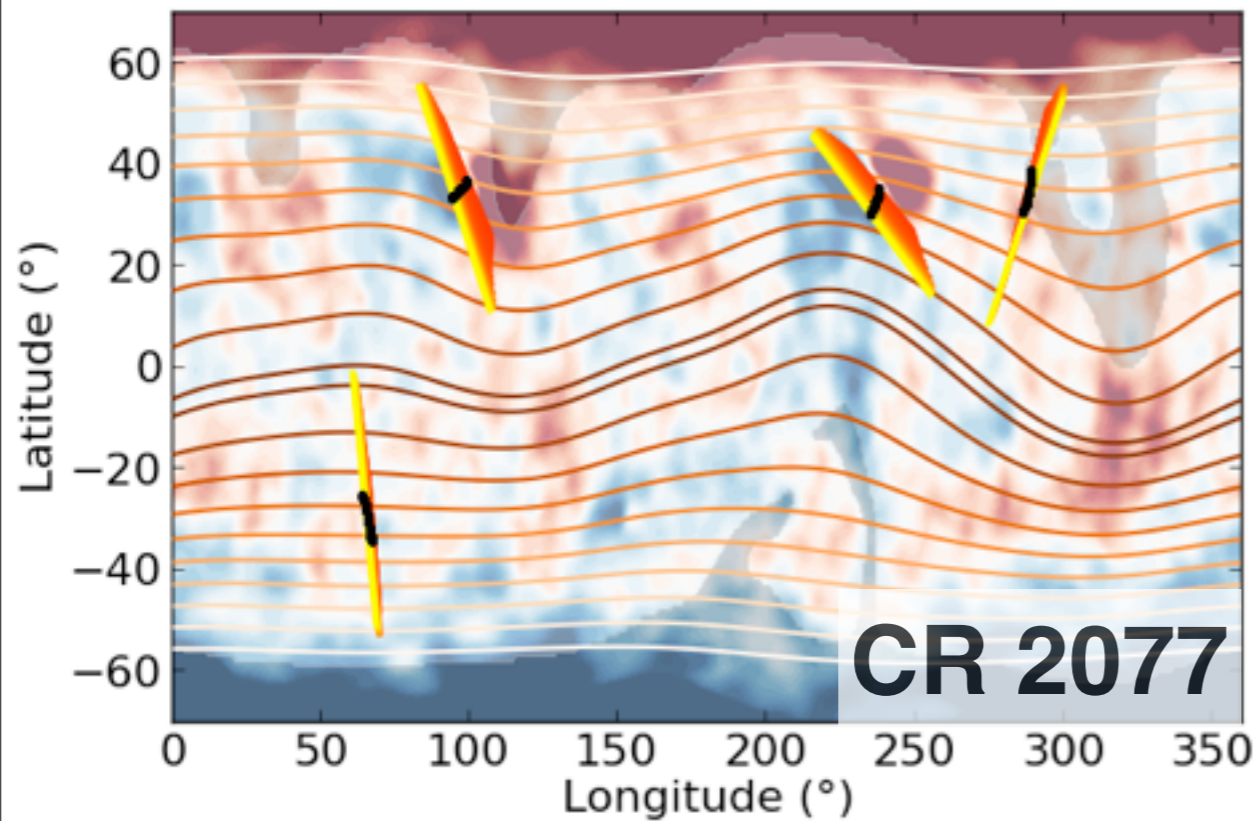


# Carrington Rotations



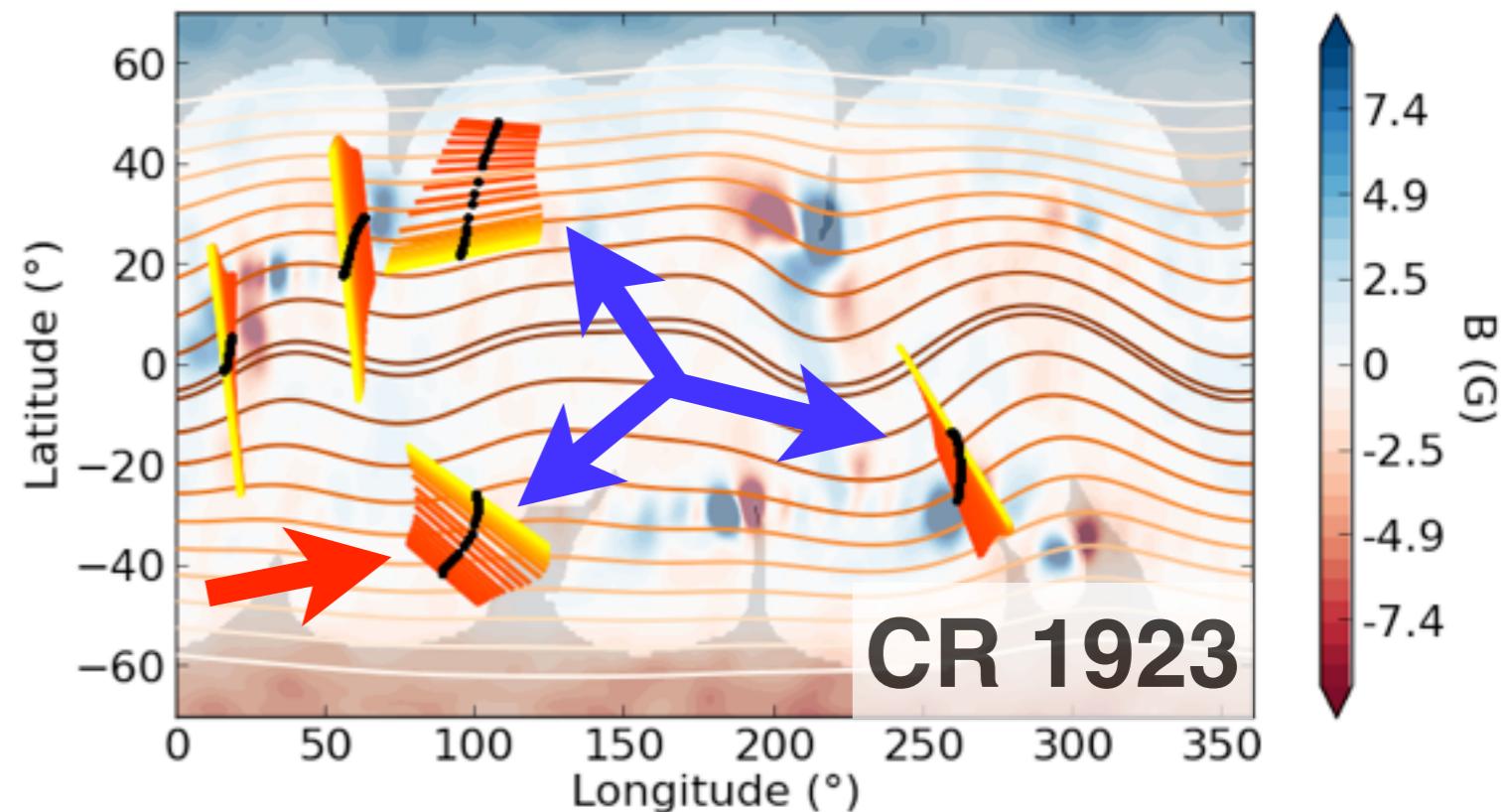
- Simulate 2 or 3 CMEs from both active regions and quiet sun for each Carrington Rotation
  - Use same CME parameters for each case

# Solar Minimum

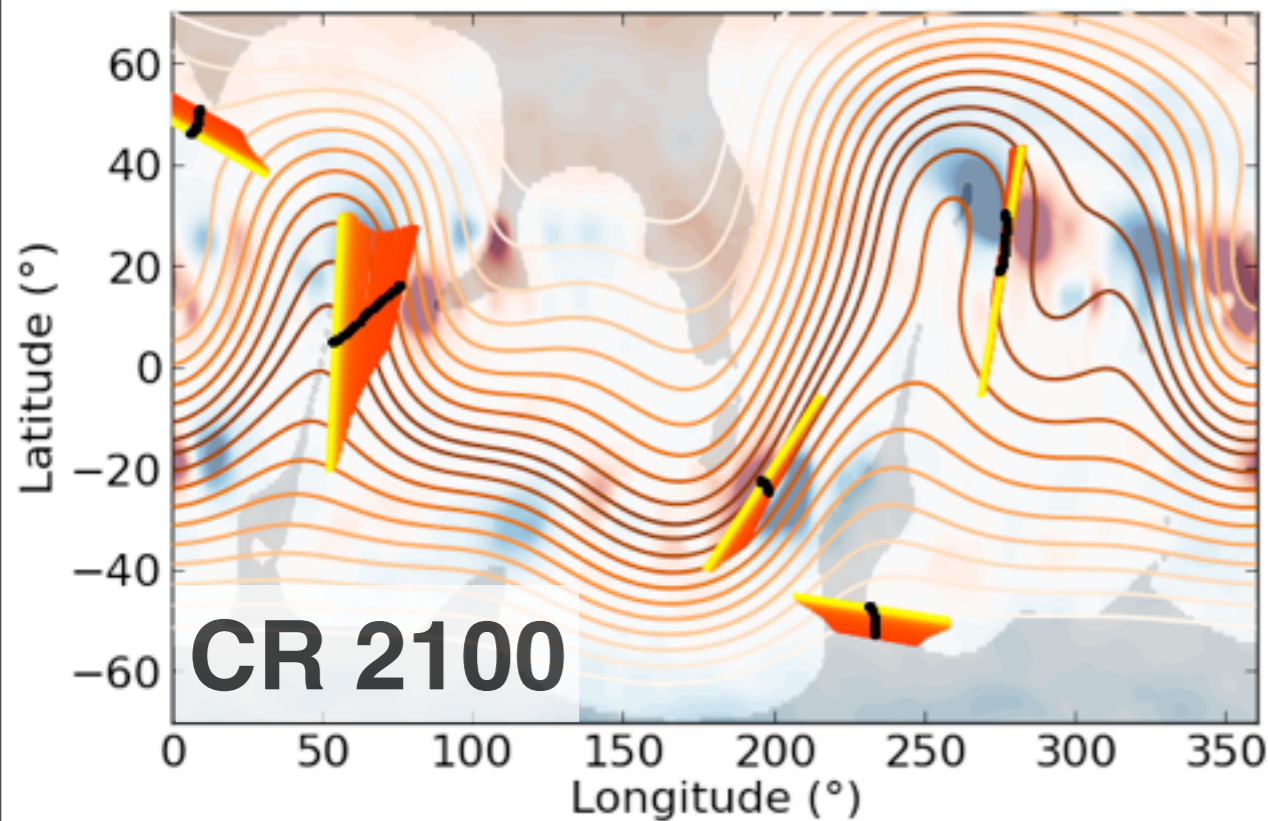


- CR 2077 very weak background -> very little deflection/rotation
- Mostly lat deflection
- AR CMEs have largest lon component

- CR 1923 has larger B and stronger def/rot
- Deflection toward HCS, some influence of CH
- Rot toward HCS?

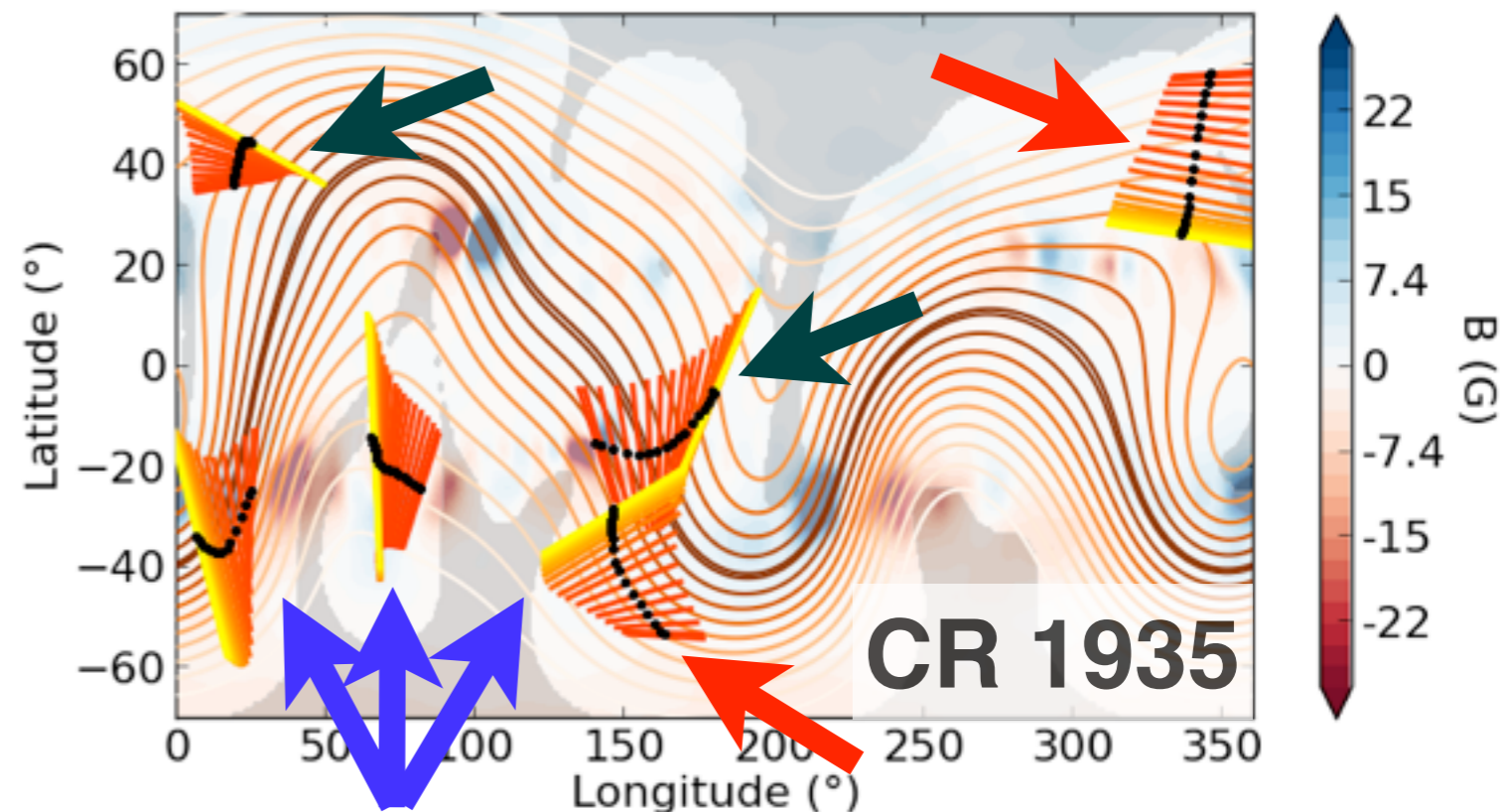


# Rising Phase

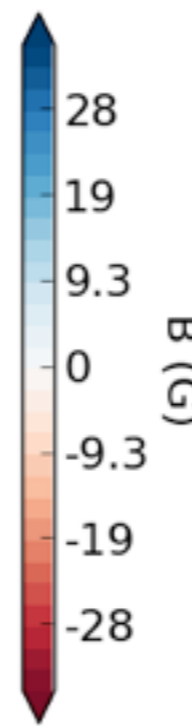
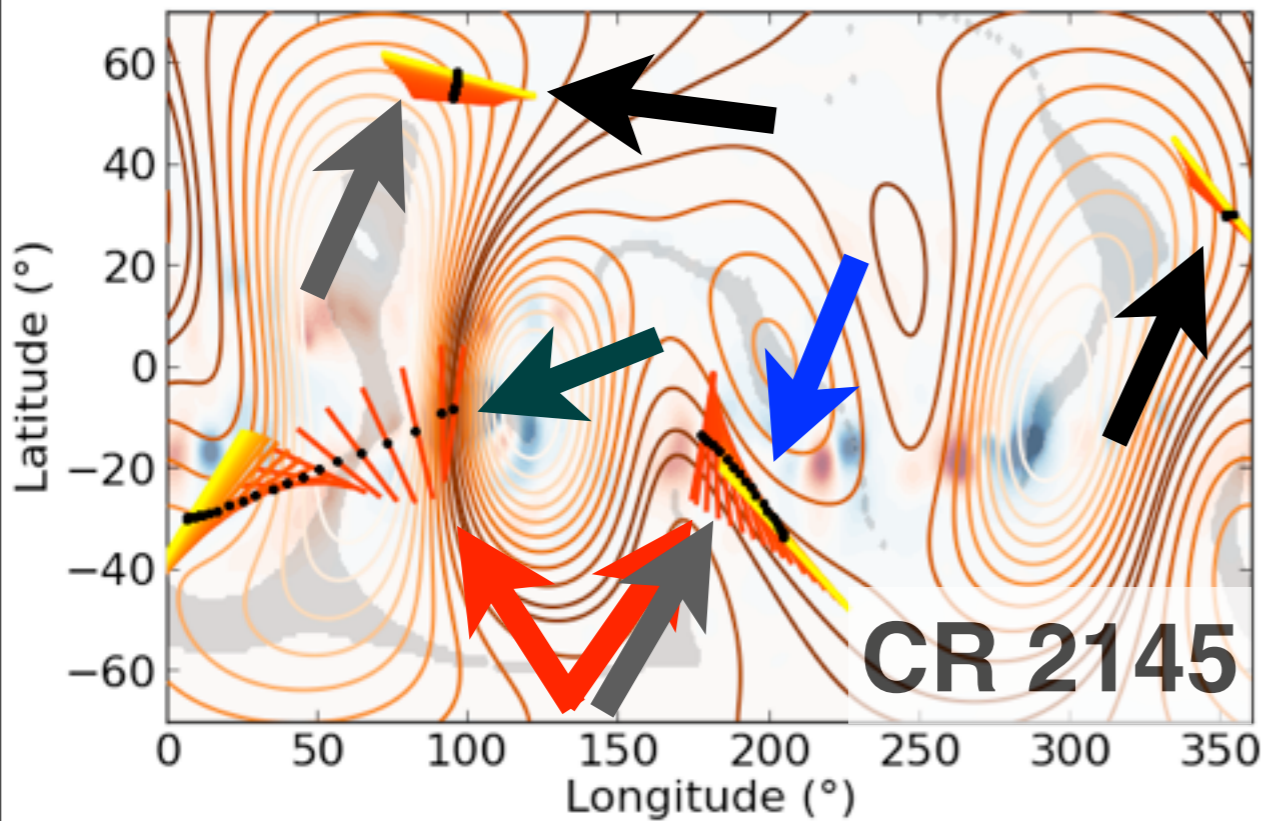


- Deflections increase in size and have larger ion component
- Quiet sun filaments can deflect as much as largest AR CME defs

- Can see effects of local AR gradients as well as HCS + CHs
- Rotation does not always align CME with HCS

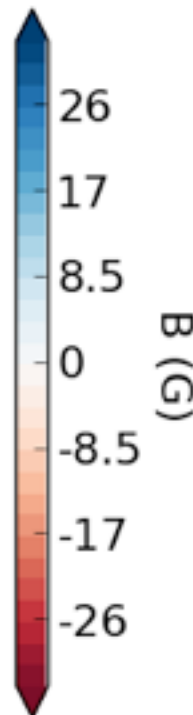
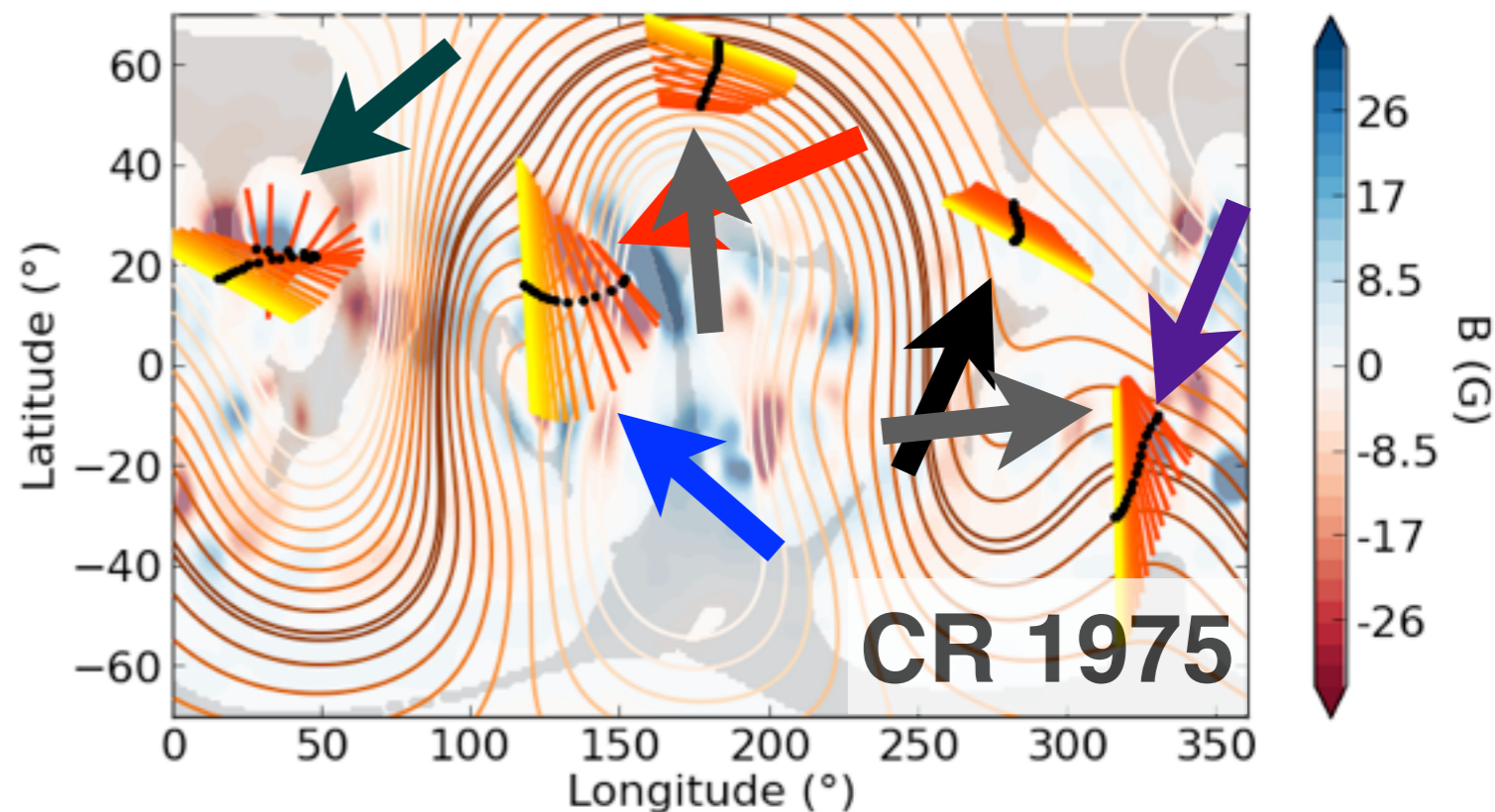


# Solar Maximum

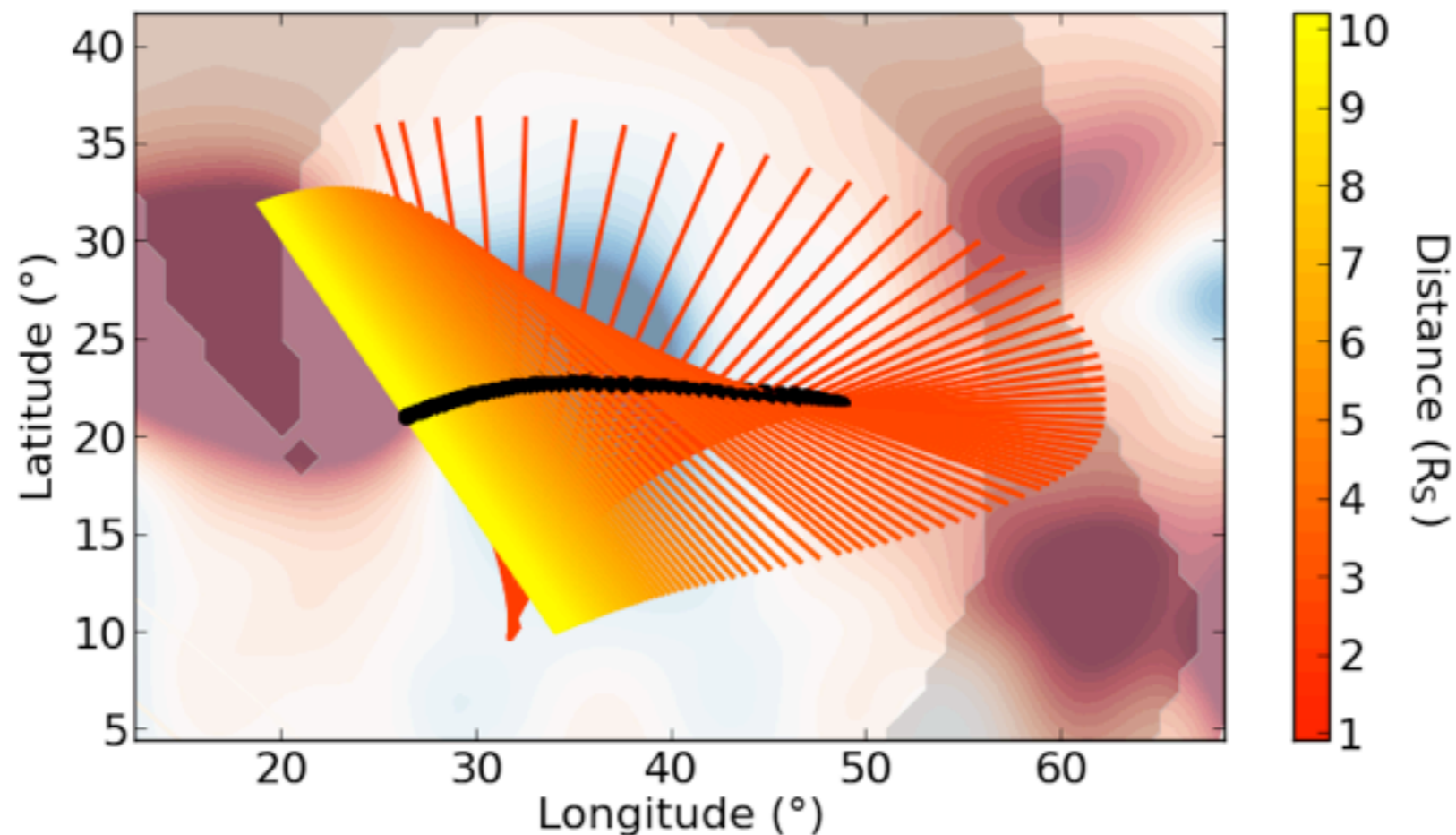


- Decrease in def of QS CMEs since near HCS
- **Large defs of AR CMEs**
- Lat def away from equator due to high lat HCS

- Sometimes rotation aligns CME with HCS
- Can get complicated behavior due to complex background

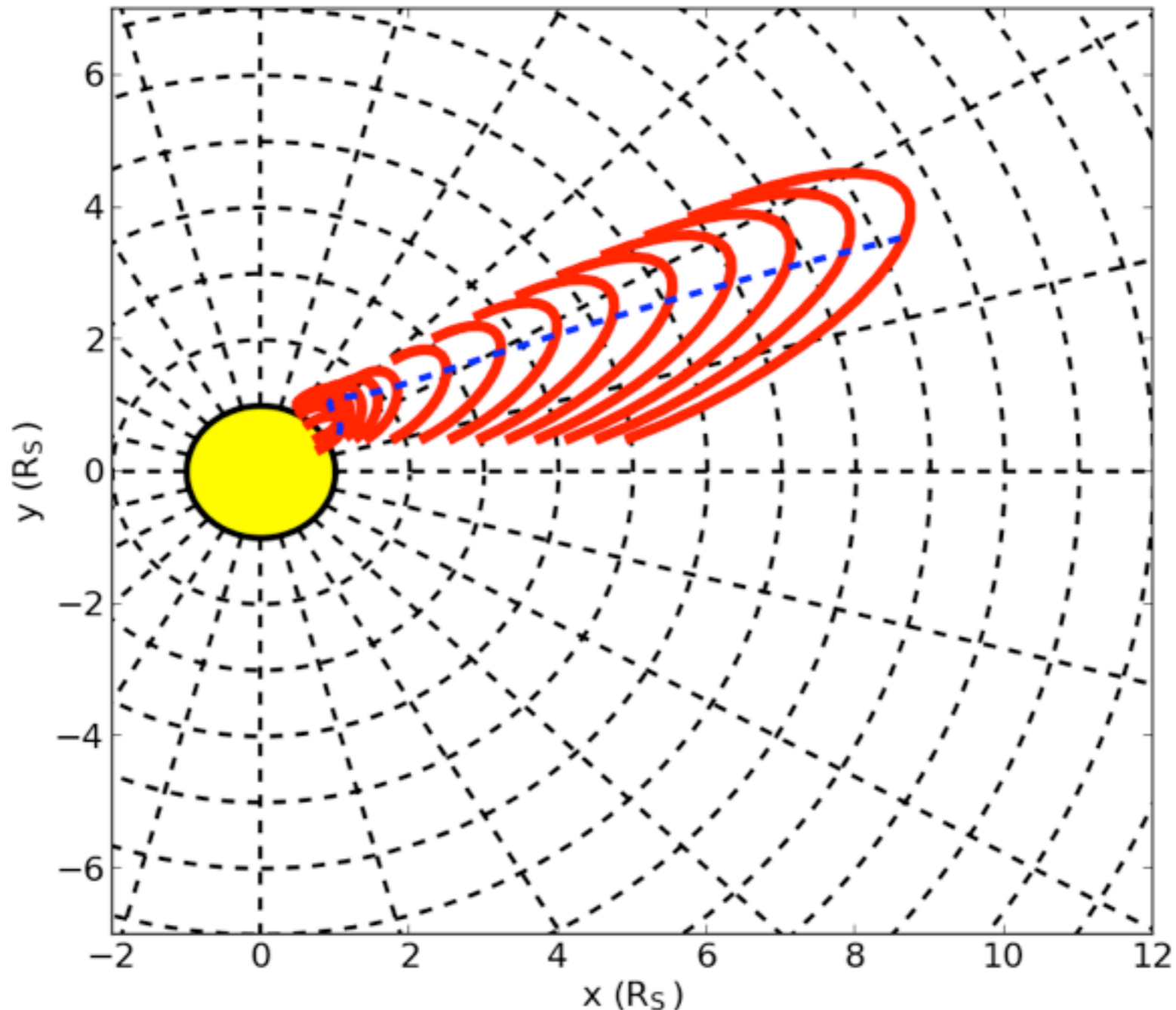


# Reflecting CME



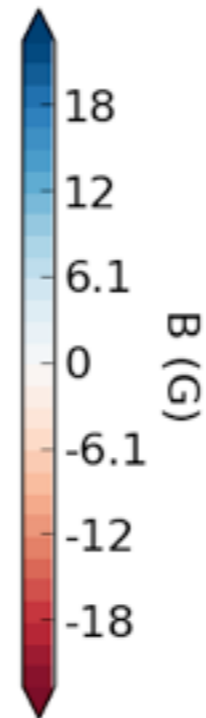
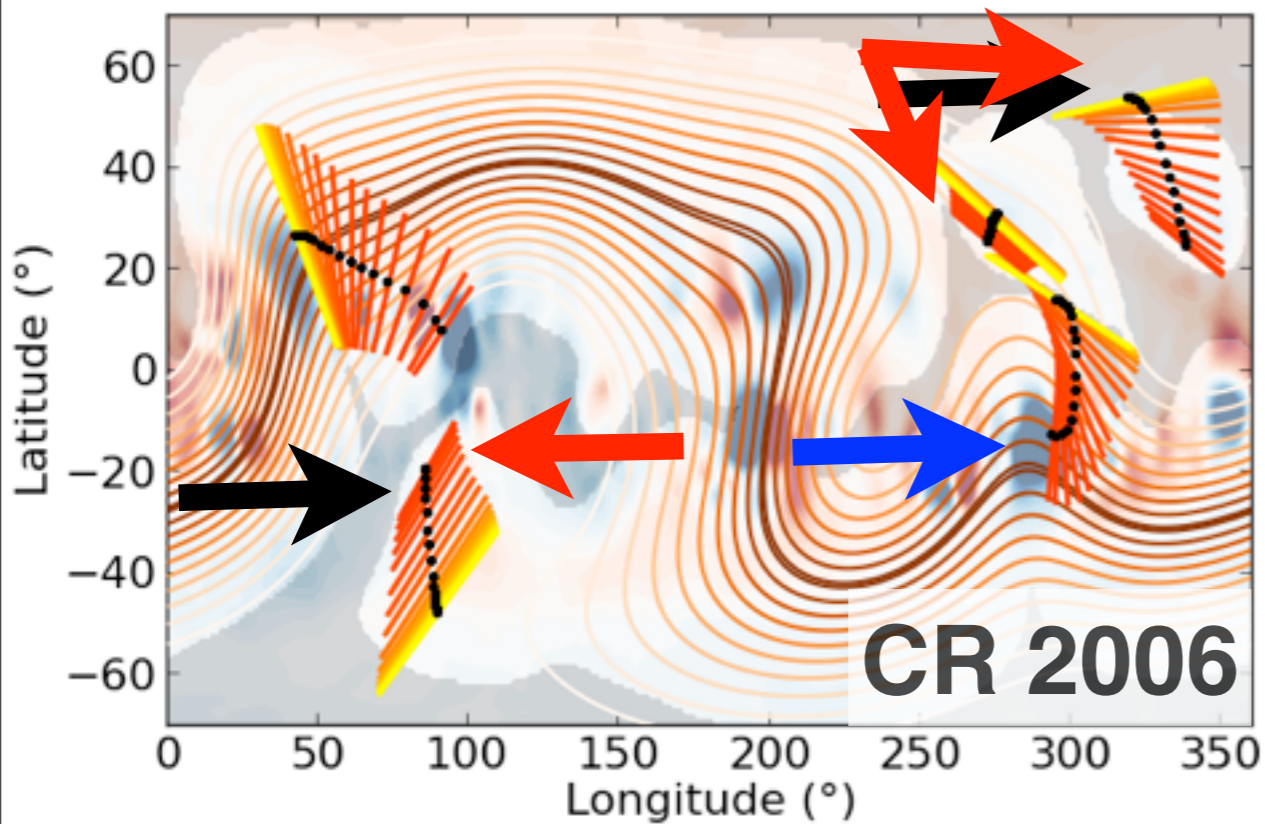
- Initially deflects away from coronal hole on left
- Reaches coronal hole on right and motion changes

# Reflecting CME



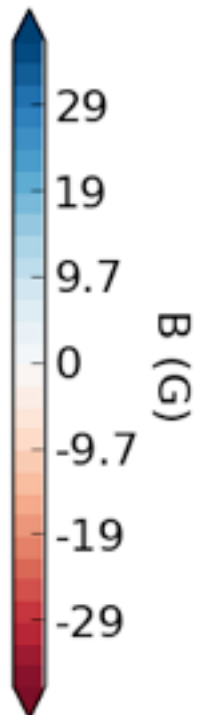
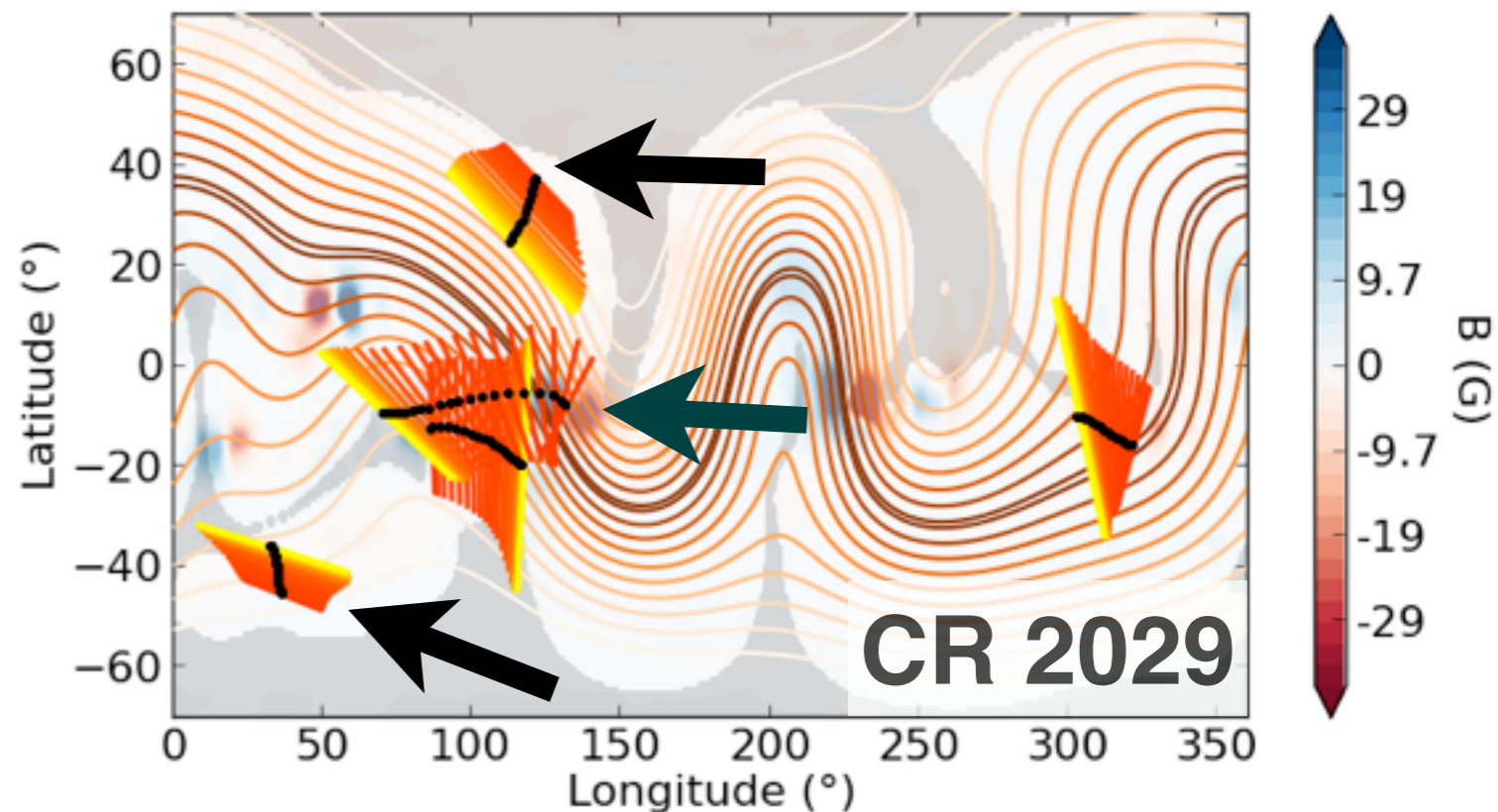
- Initially deflects away from coronal hole on left
- Reaches coronal hole on right and motion changes

# Declining Phase

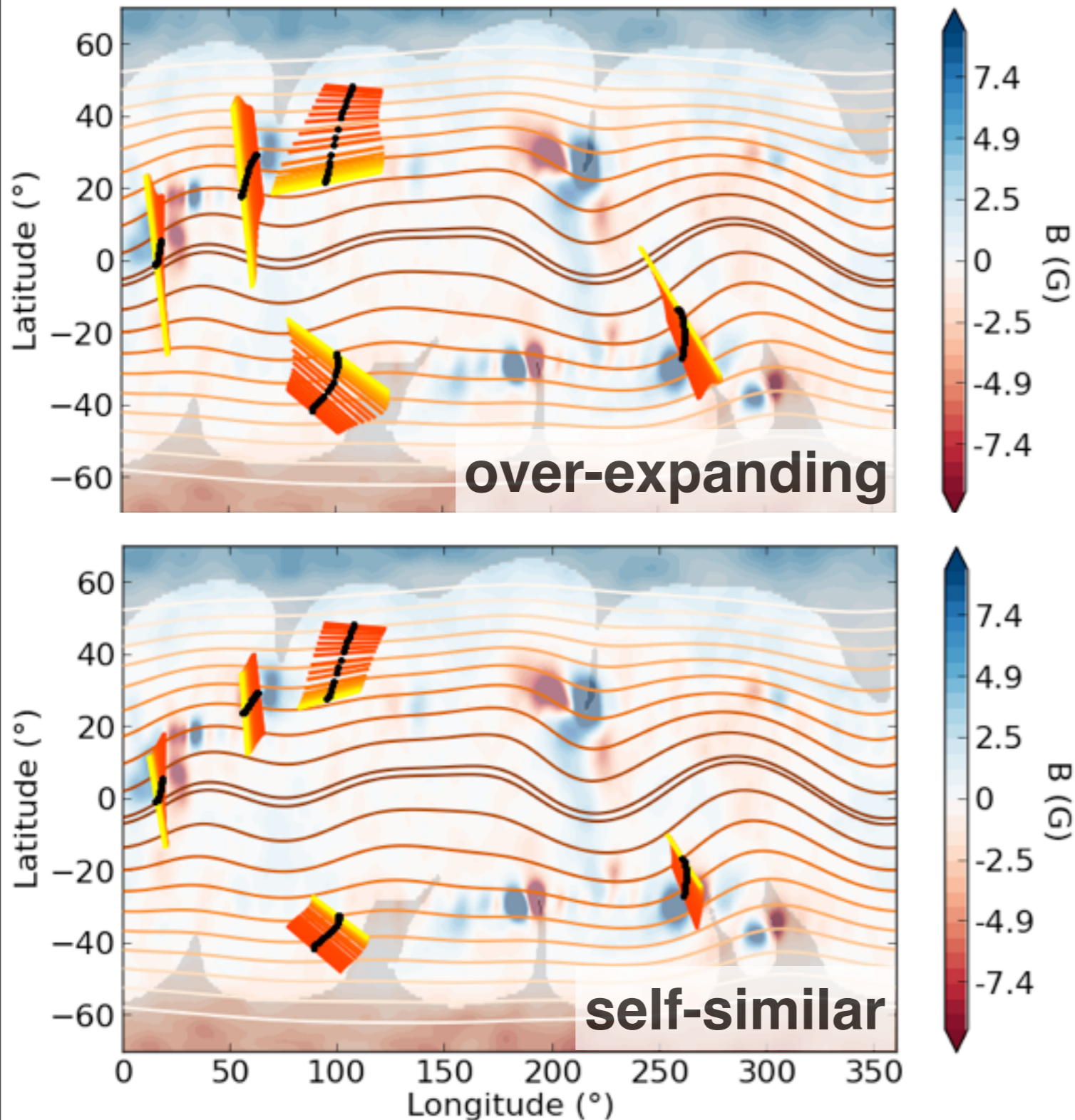


- QS deflections increase relative to max
- Lat deflection not always toward equator due to low lat CH

- Less rotation than solar max (comparable to rise)
- Rotation to align with gradients
- Rotation overshoots alignment with HCS?



# CME Expansion



- Deflection sensitive to expansion in lower corona
  - Tends to increase as over-expansion increase
  - Sometimes causes change in direction

Anomalous expansion as in SC 24 (Gopalswamy 2014)  $\rightarrow$  increase in CME deflections



# Summary/Space Weather Seasons?

## Solar Minimum

- Small def/rot
- Mostly lat def
- AR and QS CMEs can def the same amount
- HCS/CH determine direction of deflection (little AR effects)

## Rise Phase

- Def/rot increases for AR/QS CMEs
- Lon def increases due to HCS inclination and strength of ARs
- AR/QS CMEs def similar amounts
- AR CMEs have larger lon def than QS
- ARs/CHs/HCS influence direction of def
- Rotation sometimes aligns CME with HCS

## Solar Maximum

- Largest def/rot for AR CMEs
- Decrease in QS CME def due to proximity of high lat HCS
- Def away from equator due to high lat HCS
- AR CMEs have larger lon def than QS
- ARs/CH/HCS influence def direction
- Rotation sometimes aligns with HCS

## Declining Phase

- AR/QS def/rot comparable to rise phase (AR less, QS more relative to solar max)
- Lat def away from equator due to low lat CHs
- AR/QS CMEs def similar amounts
- AR CMEs have larger lon def than QS
- ARs/CH/HCS influence def direction
- Rotation sometimes aligns with HCS

# Implications

- On “average” CMEs deflect away from coronal holes toward the Heliospheric Current Sheet
  - Direction varies as the relative location of ARs, CHs, and the HCS changes throughout the solar cycle
  - Magnitude increases with solar magnetic field strength
  - Rotation towards aligning with HCS?
- Near solar max strong ARs can cause large longitudinal deflections and rotations deviating from “average” behavior
- “Seasonal” variation in Earth impacts?
  - Solar min - small defs, but primarily Earth/equator-ward
  - Solar max - large defs, but can deflect toward or away
  - Declining/rise somewhere in between, but with largest QS CME defs