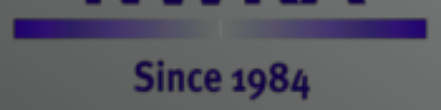
Statistical analysis of the evolution of active region tilt angles

Hannah Schunker

A.C. Birch, D.C. Braun, R.H. Cameron, L. Gizon, R. Burston



Importance of Joy's Law

Flux tubes form somewhere in the interior

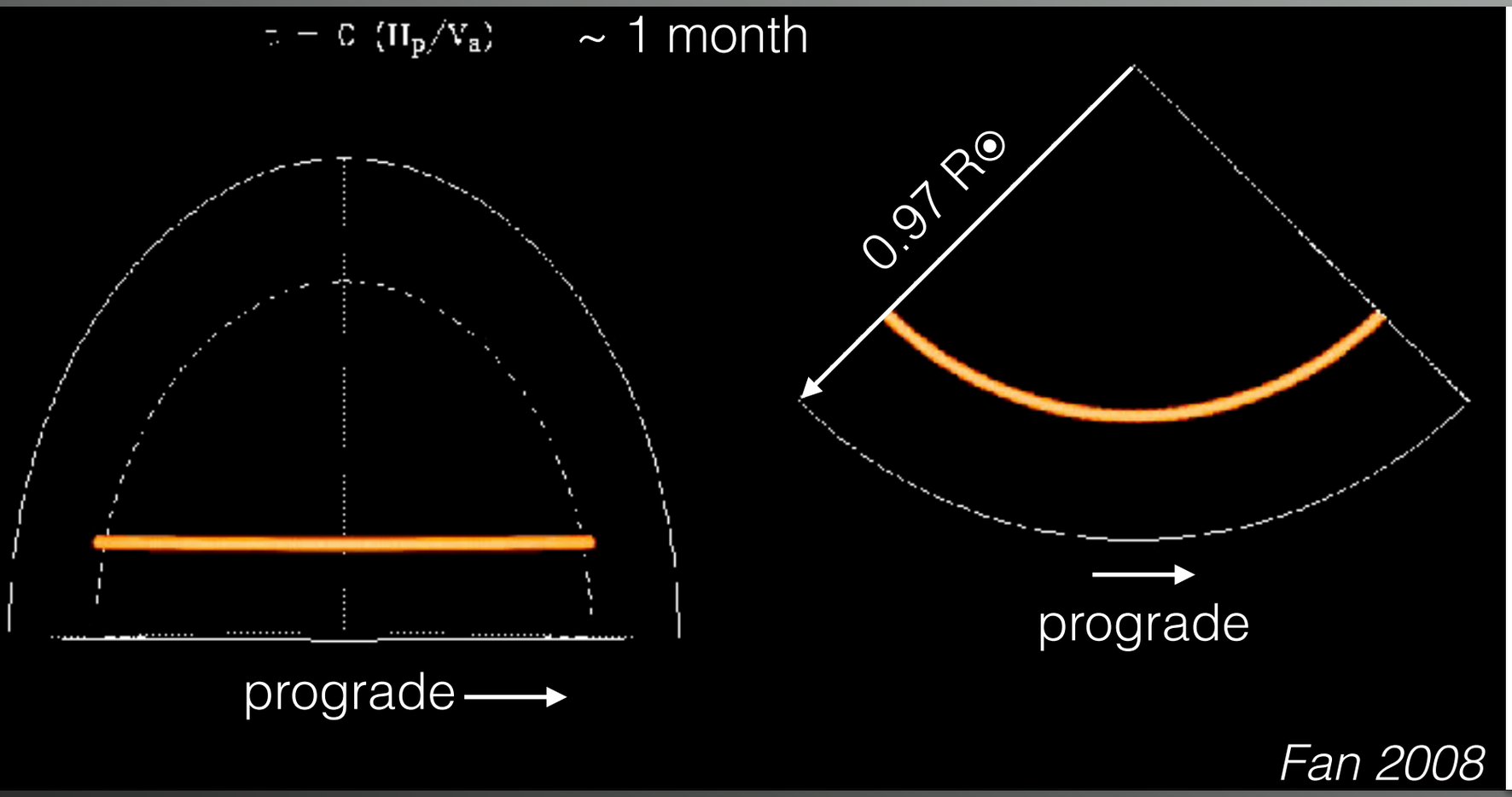
- below the convection zone *e.g. Zwaan 1978; Spiegel & Weiss 1980*
- in the convection zone *e.g. Charbonneau 2005; Nelson et al 2013*
- close to the surface *e.g. Brandenburg 2005*

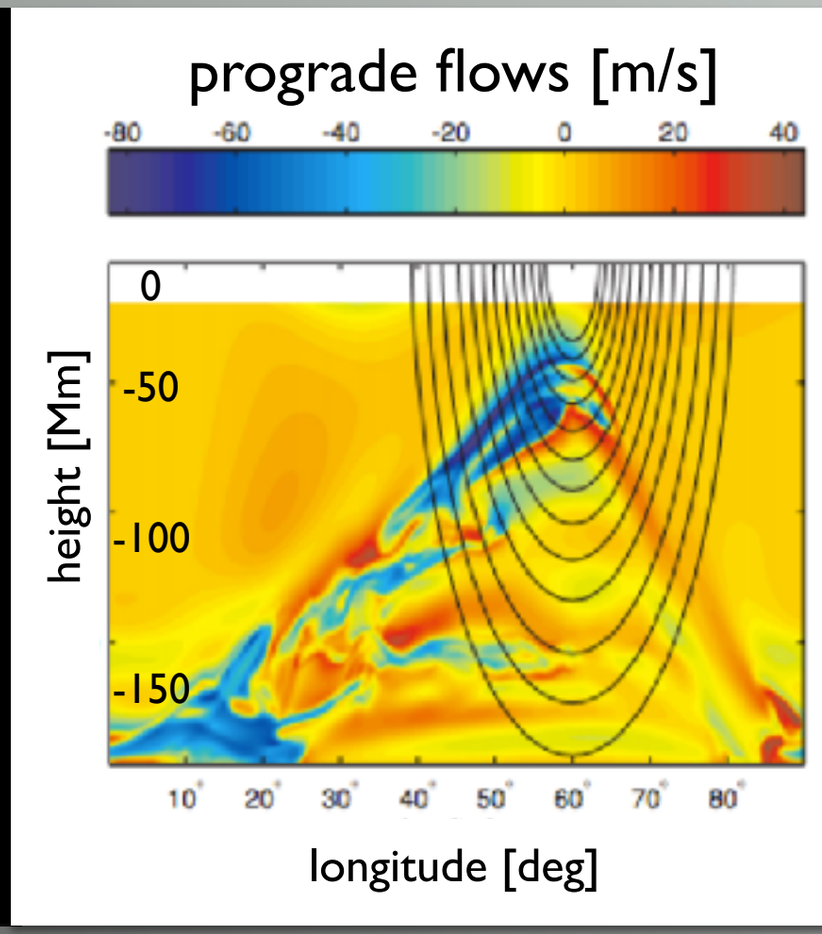
Onset and evolution of the tilt angle helps us to understand the origin of surface activity

Joy's Law crucial to surface flux transport & Babcock-Leighton dynamo model

e.g. Jiang et al 2014; Dasi-Espuig et al 2010; Cameron et al 2016

Origin of Tilt Angle





Coriolis force acting on East-West flows in the flux tube as it rises through the convection zone

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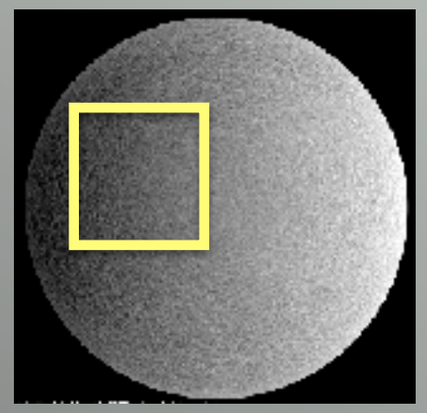
SDO Helioseismic Emerging Active Region Survey

185 ‘clean’ Emerging Active Regions (EARs) + control regions
April 2010 to July 2014

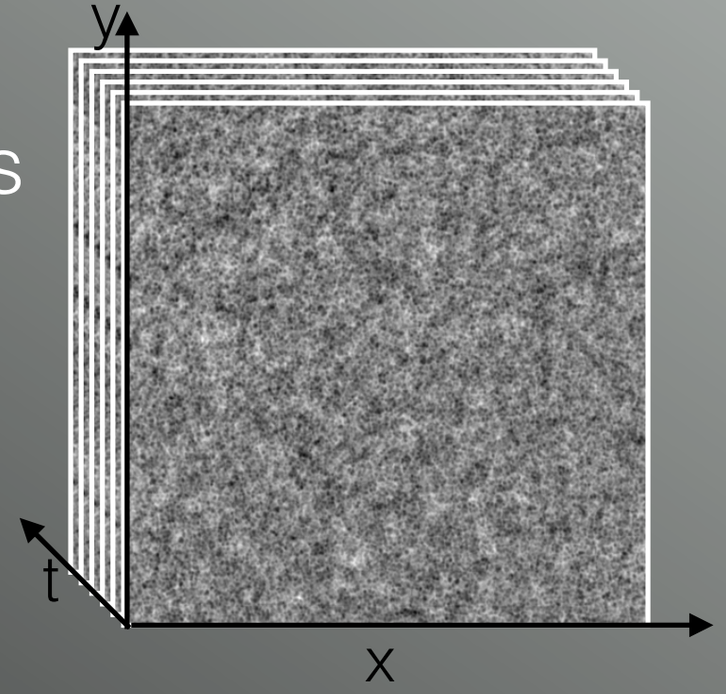


60 degree square Postel projected maps

Tracked at the Carrington rotation rate
up to 7 days pre- / post-emergence, 45s cadence

Mapped and tracked datacubes every ~6 hours

intensity —> averaged continuum images
l.o.s. magnetic field —> averaged magnetograms
velocity —> travel-times for waves with turning point
up to 70 Mm below surface
(not inversions!)



Computed by and stored at the German Data Centre for SDO
(~15 TB)

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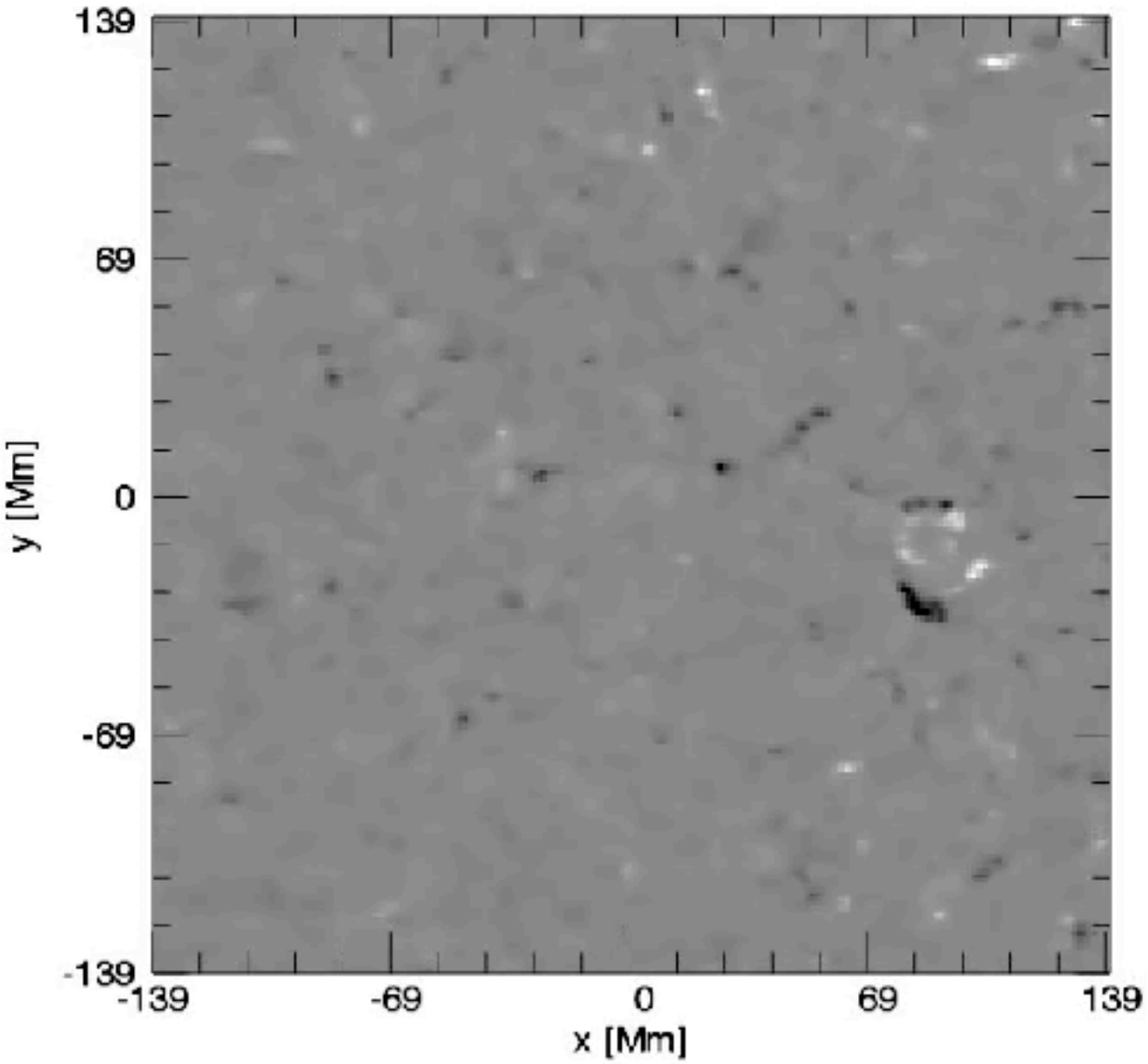
Example EARs

SDO / HMI monitoring campaigns allow statistical studies

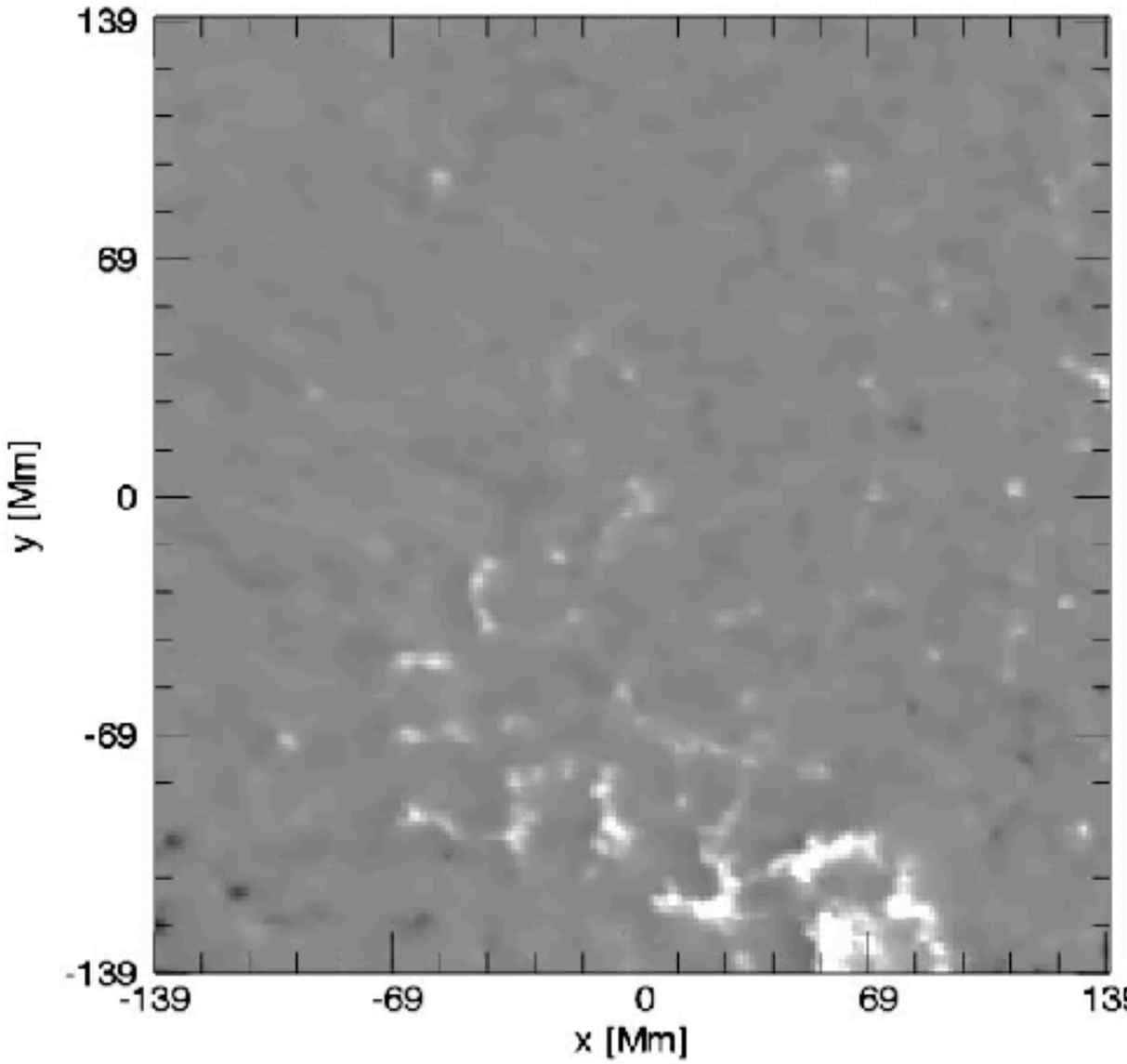
Kosovichev & Stenflo 2008, Stenflo & Kosovichev 2012, McClintock & Norton 2016

6 hour averaged l.o.s magnetic field maps

AR11158 -2.1 days

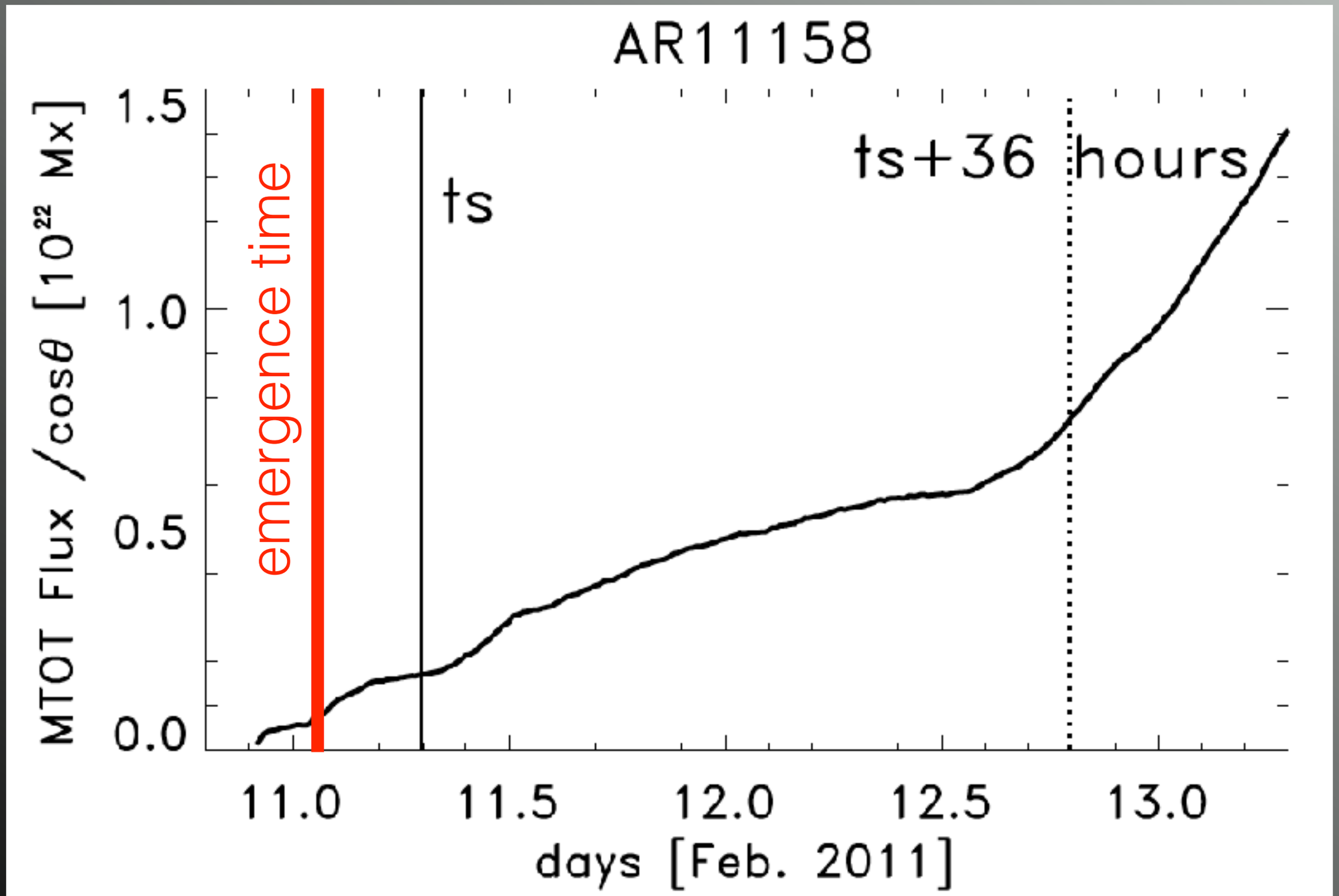


AR11209 -3.4 days



-100 G < **B** < 100 G

Defining the Emergence Time



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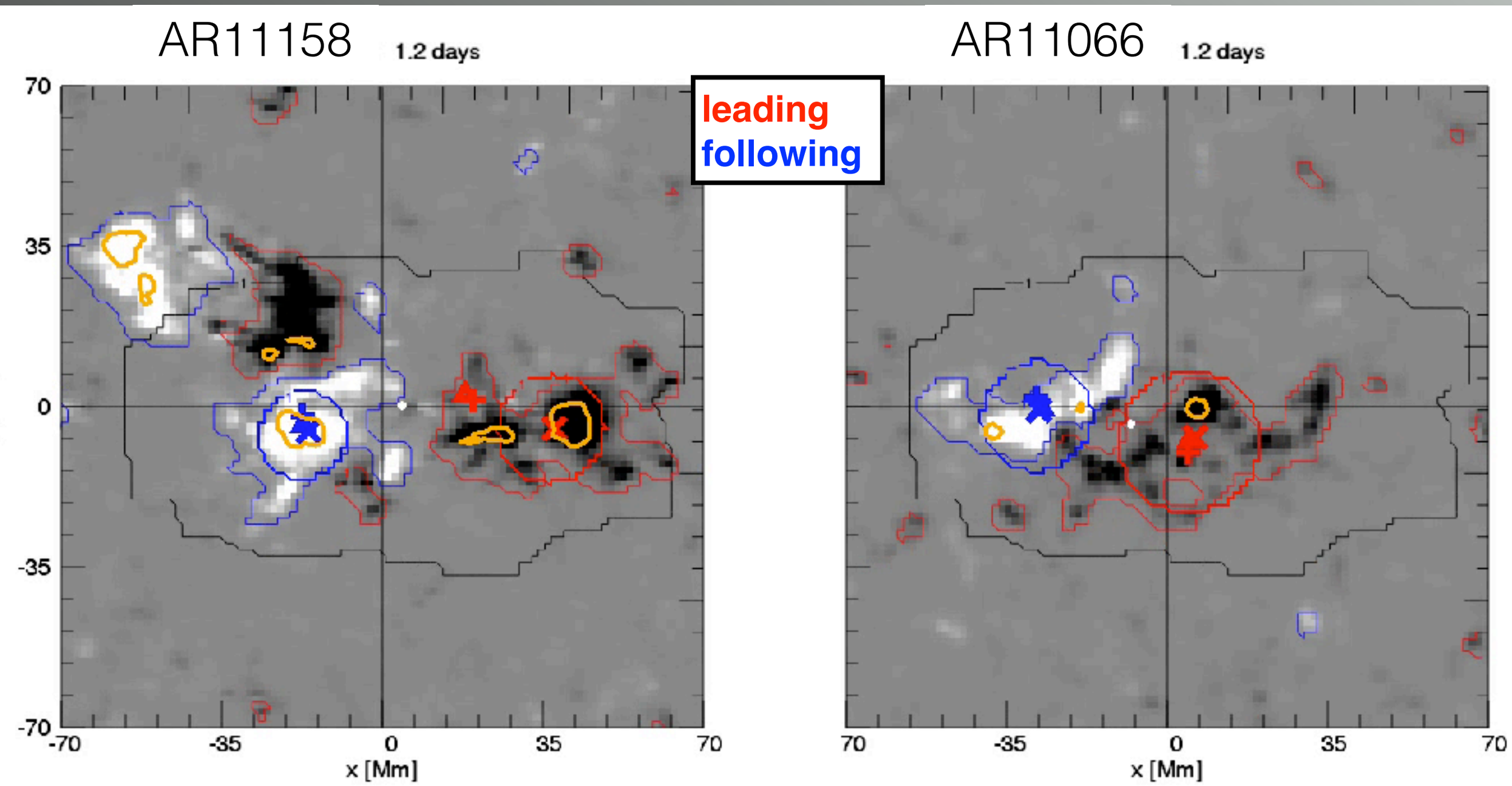
Measuring the location of the polarities

Location identified at 0.5 days and tracked forward/back in time



x feature identification **+ flux weighted c.o.g.** **Δ flux c.o.g.**

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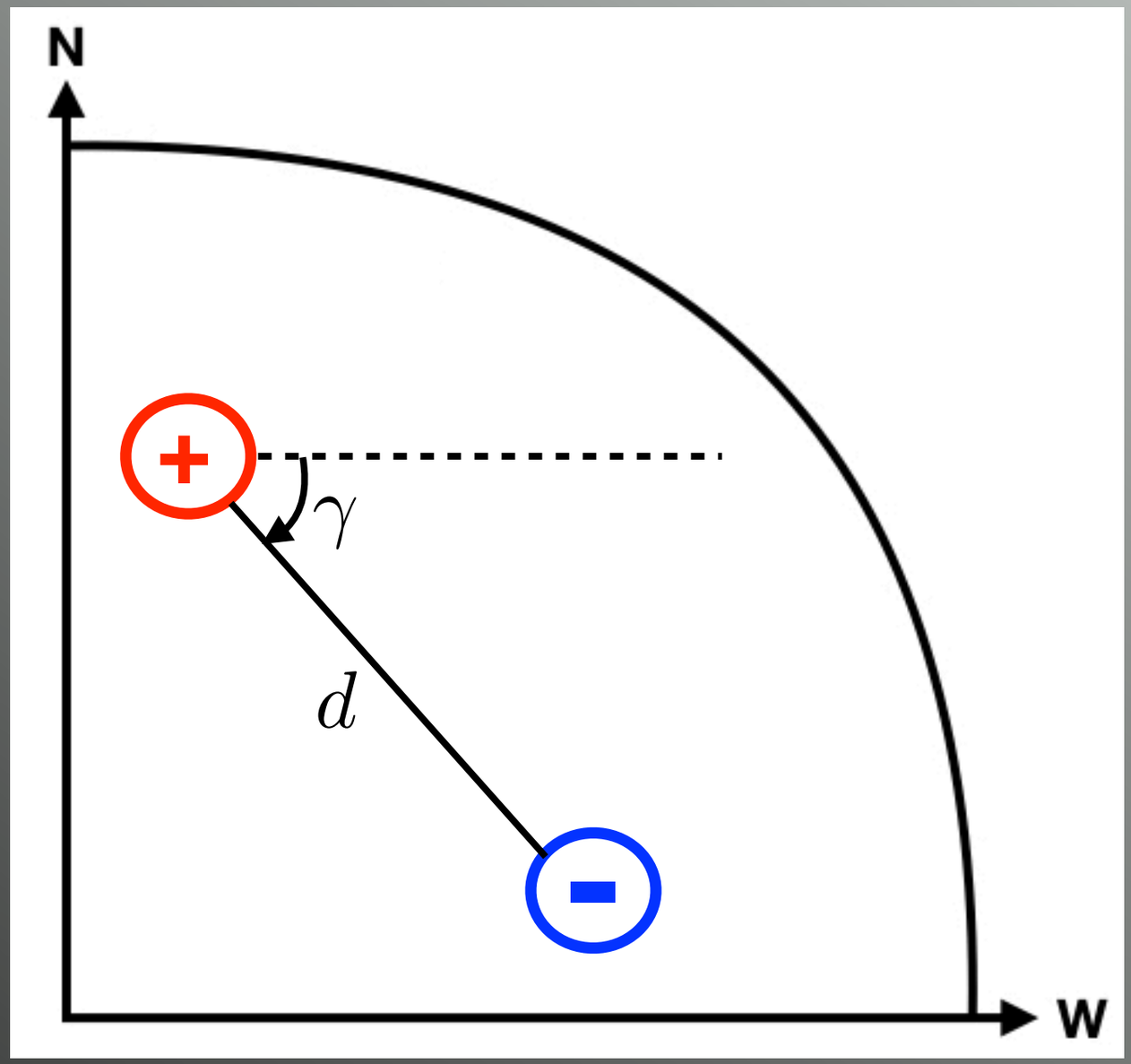
Definition of Coordinates

Relative separation

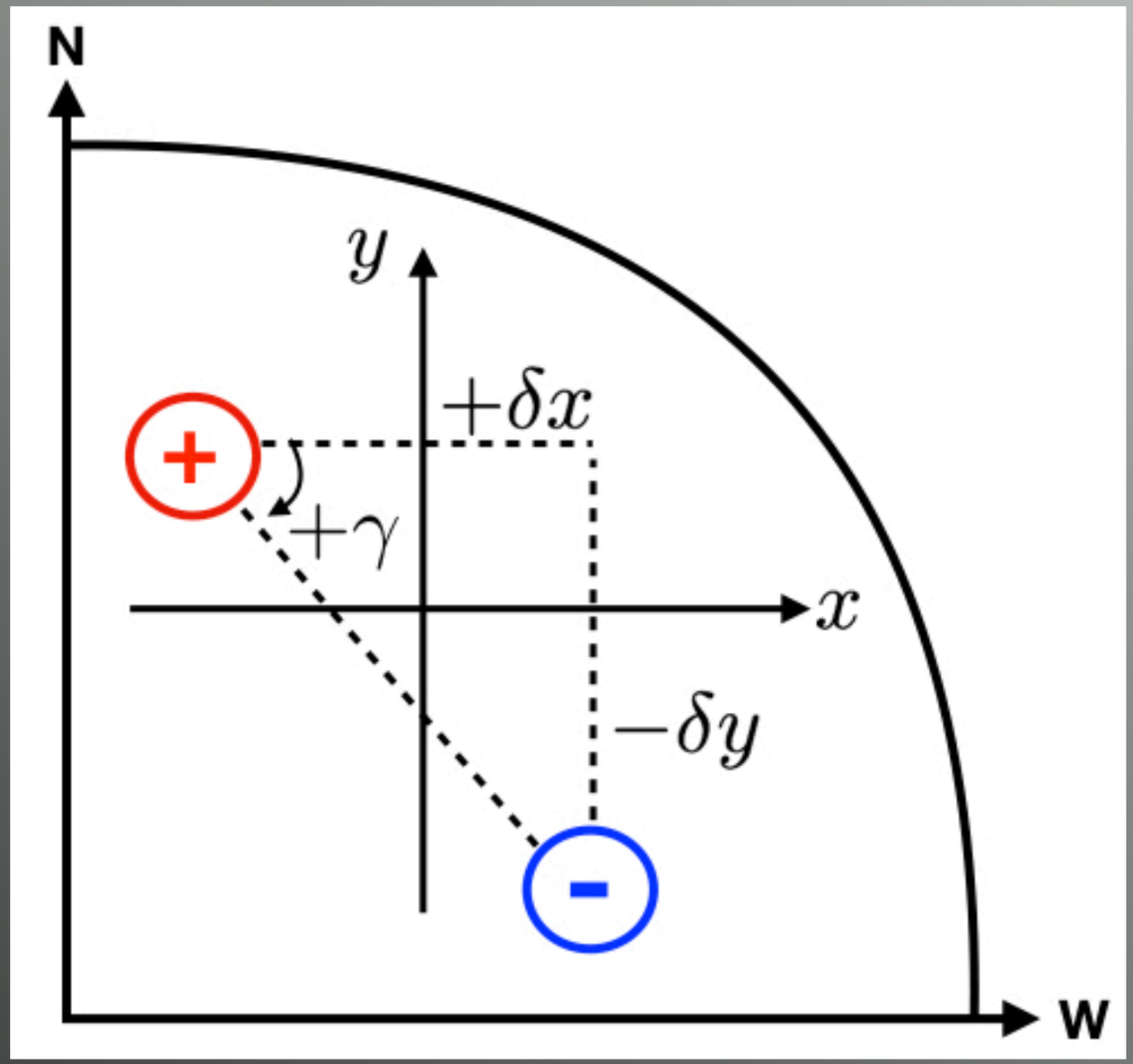


Definition of Coordinates

First time independent motion of the polarities in longitude and latitude has been analysed statistically

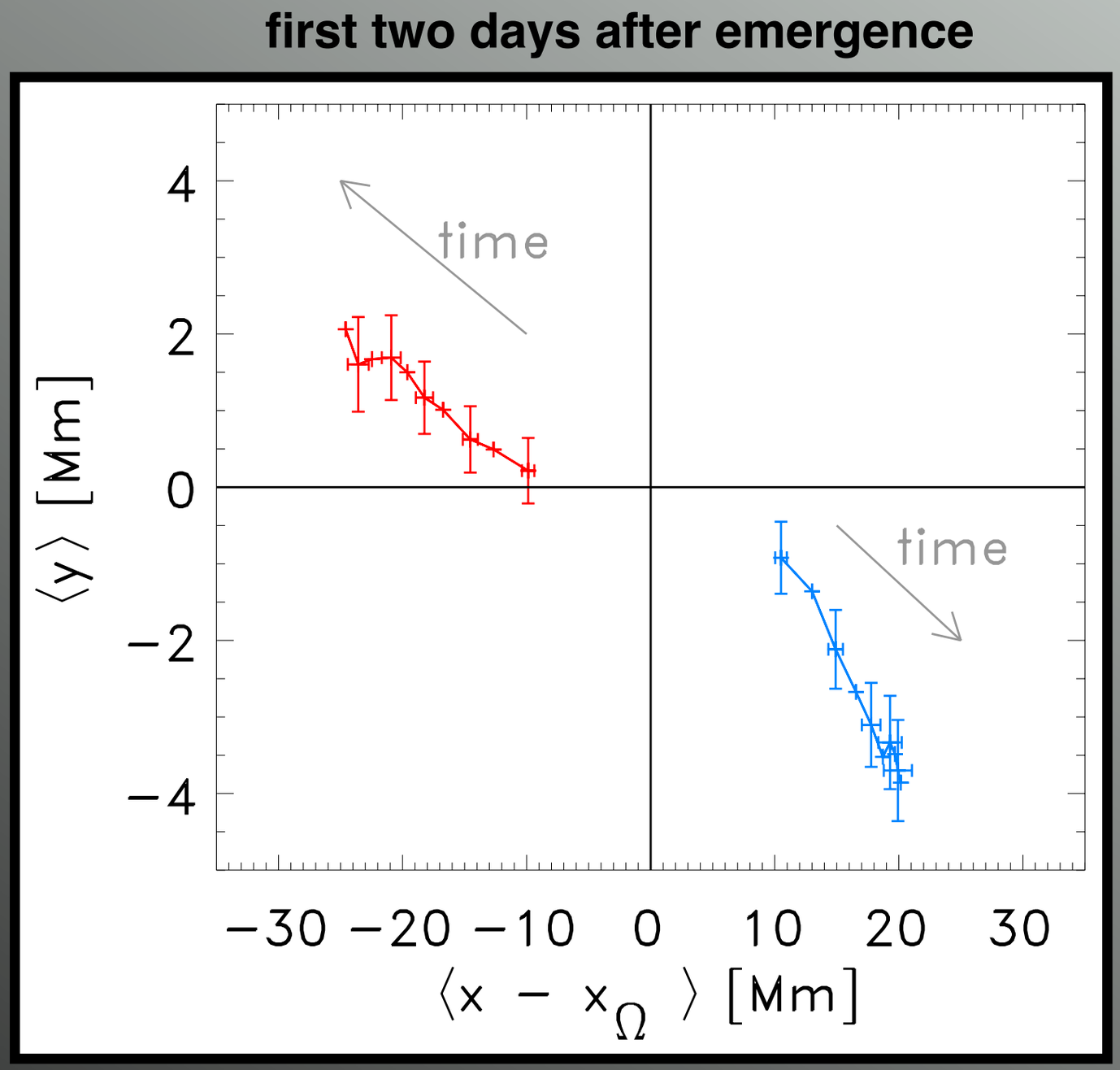
Position relative to flux weighted centre

Relative longitudinal and latitudinal separation



Average Motion of Polarities

First time independent motion of the polarities in longitude and latitude has been analysed statistically

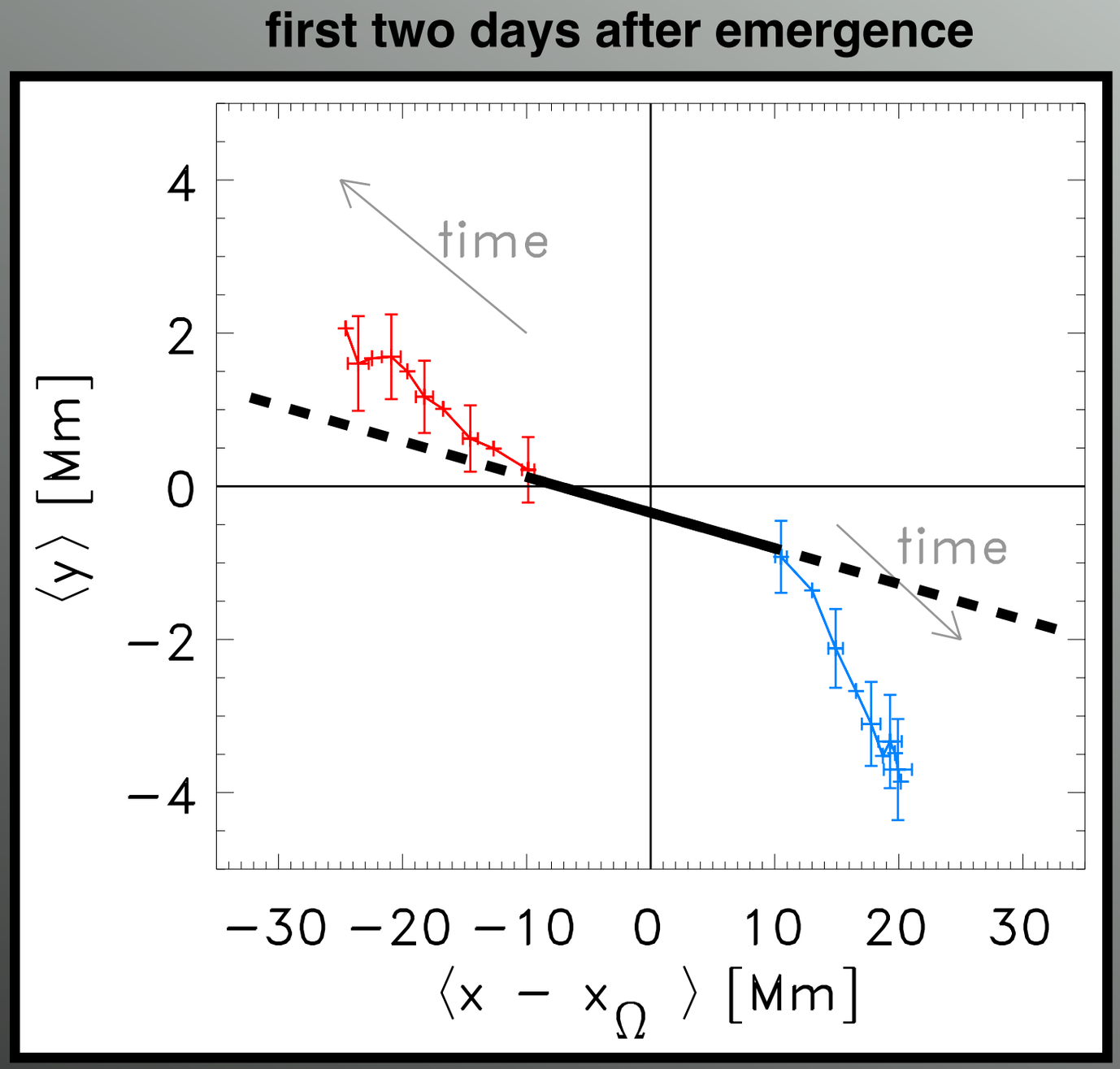


Excludes Constant Tilt Angle Model

First time independent motion of the polarities in longitude and latitude has been analysed statistically

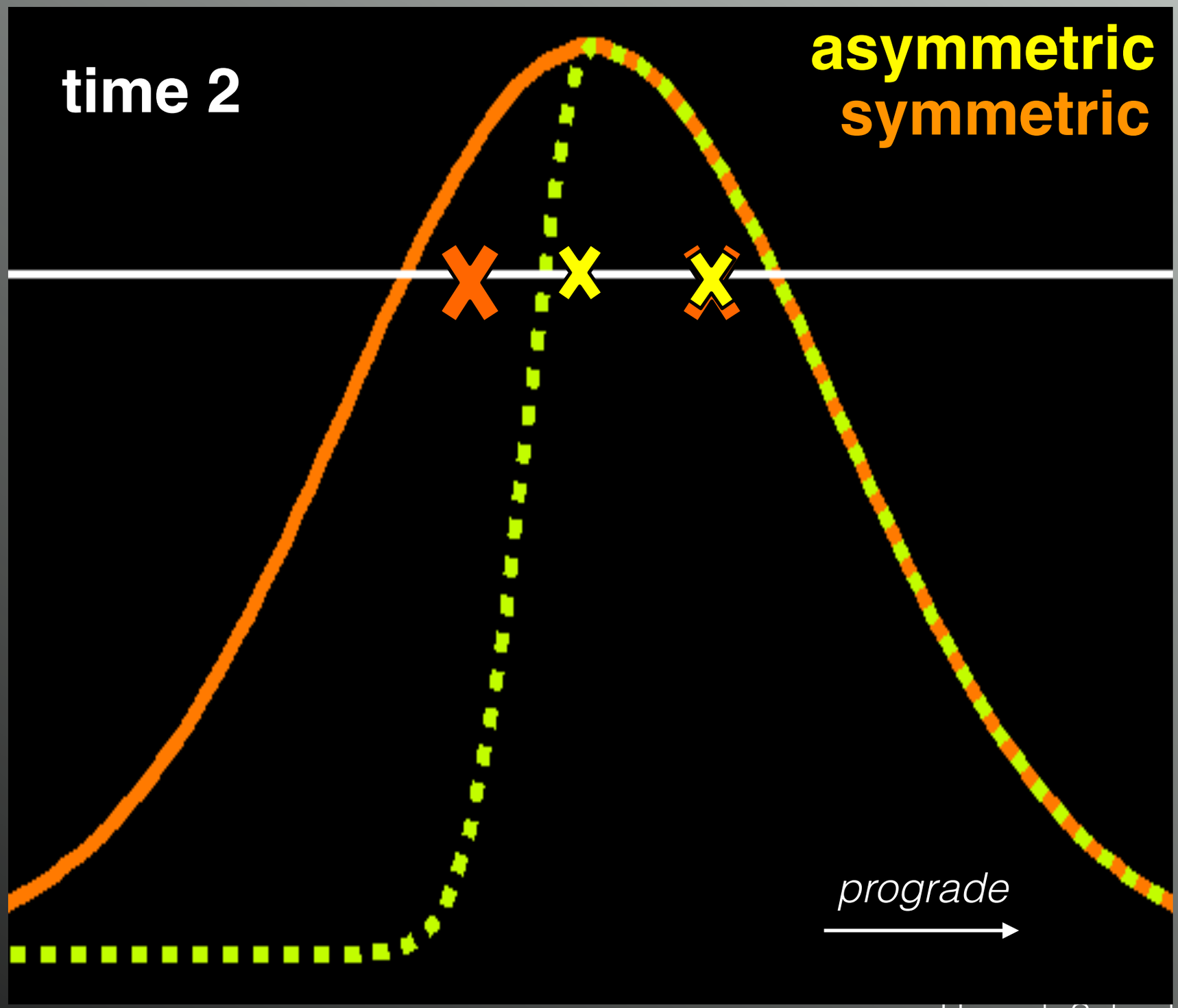
Emerge roughly E-W aligned

Tilt increases



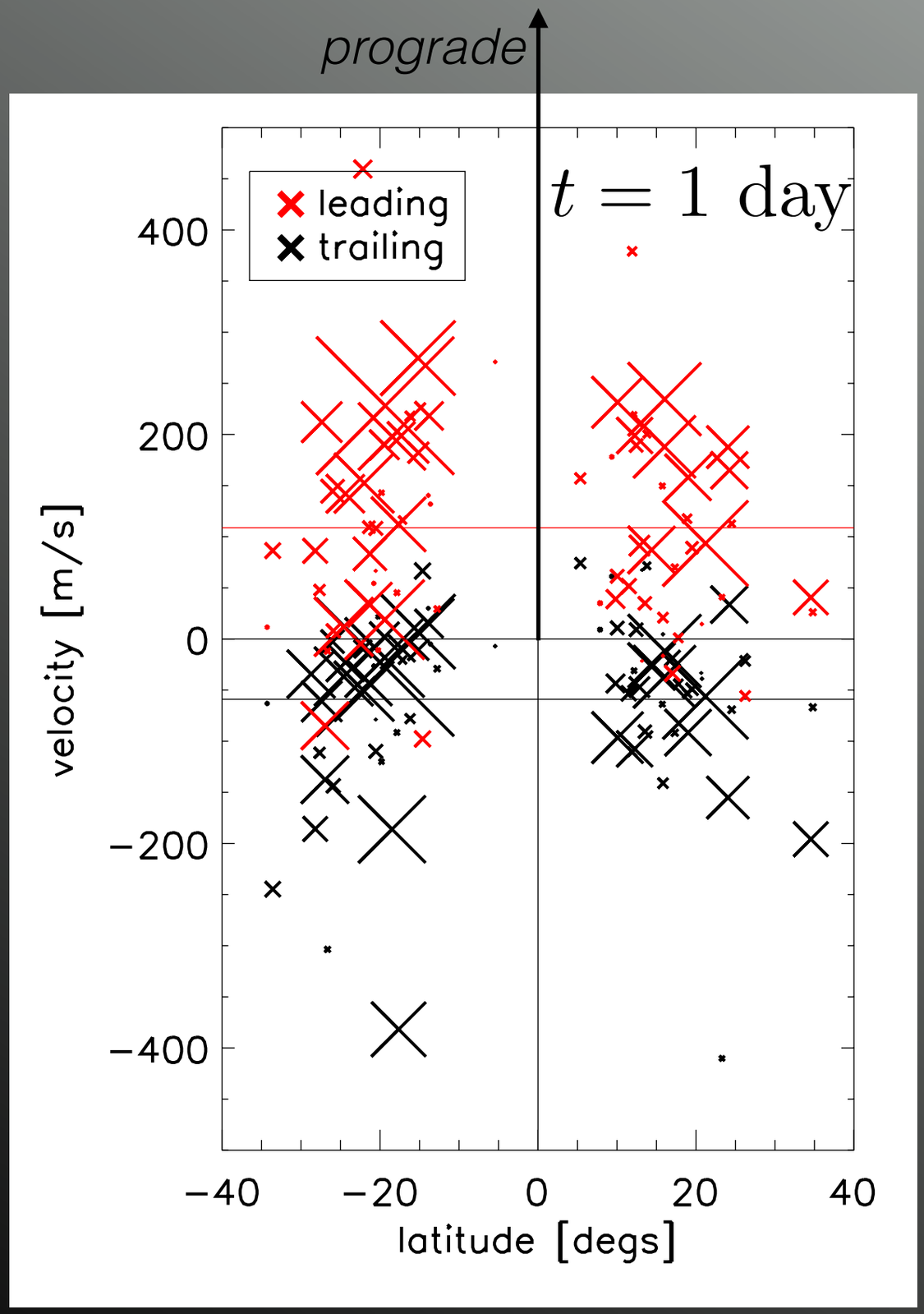
Asymmetry of the Flux Tube

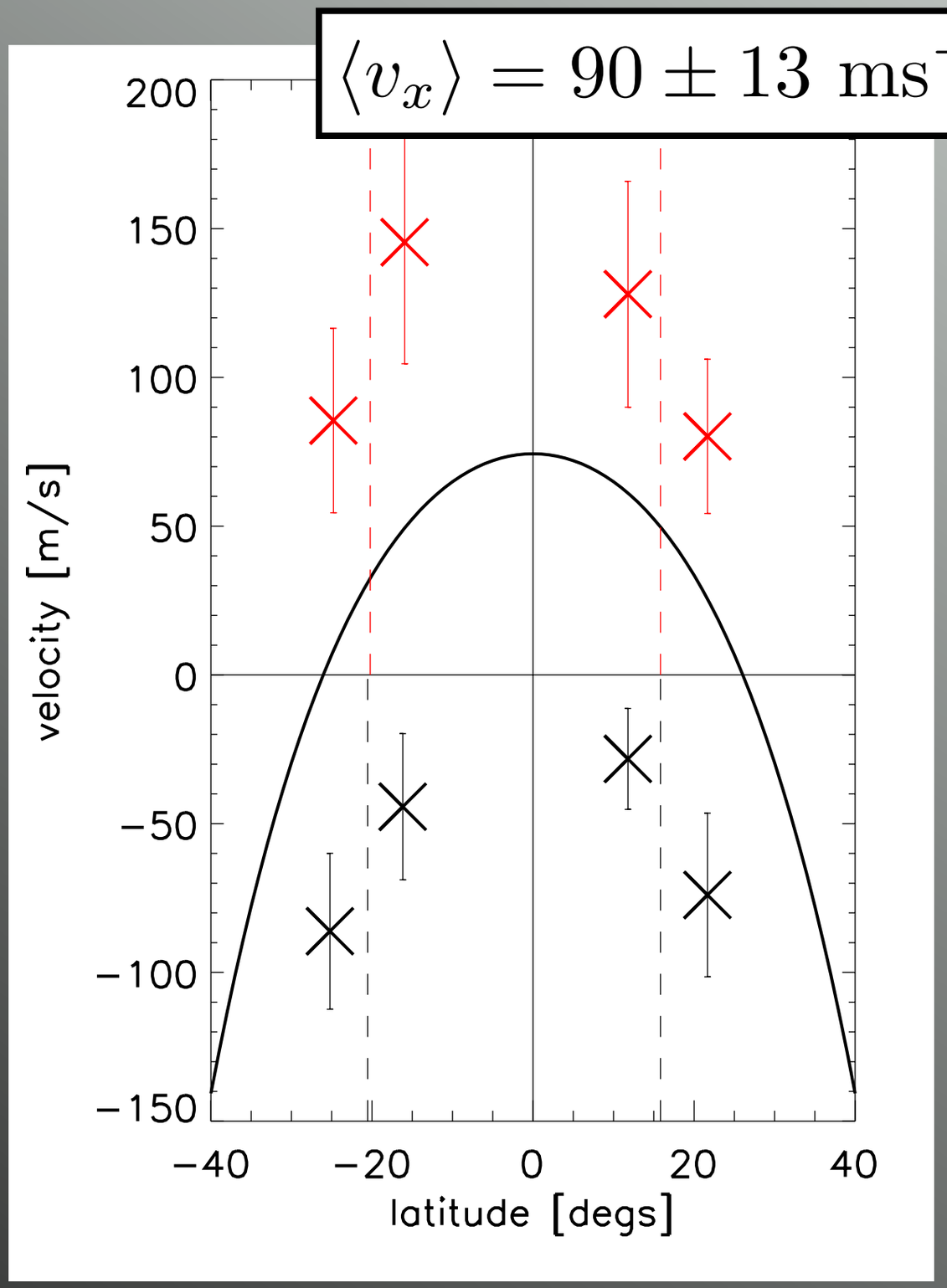
Asymmetric
e.g.
Chou & Wang 1987;
van Driel-Gesztelyi & Petrovay 1990;
Petrovay et al 1990



Leading polarity moves further in the prograde direction than the following polarity, in the retrograde direction.

Longitudinal Separation of Polarities





Schunker et al 2016

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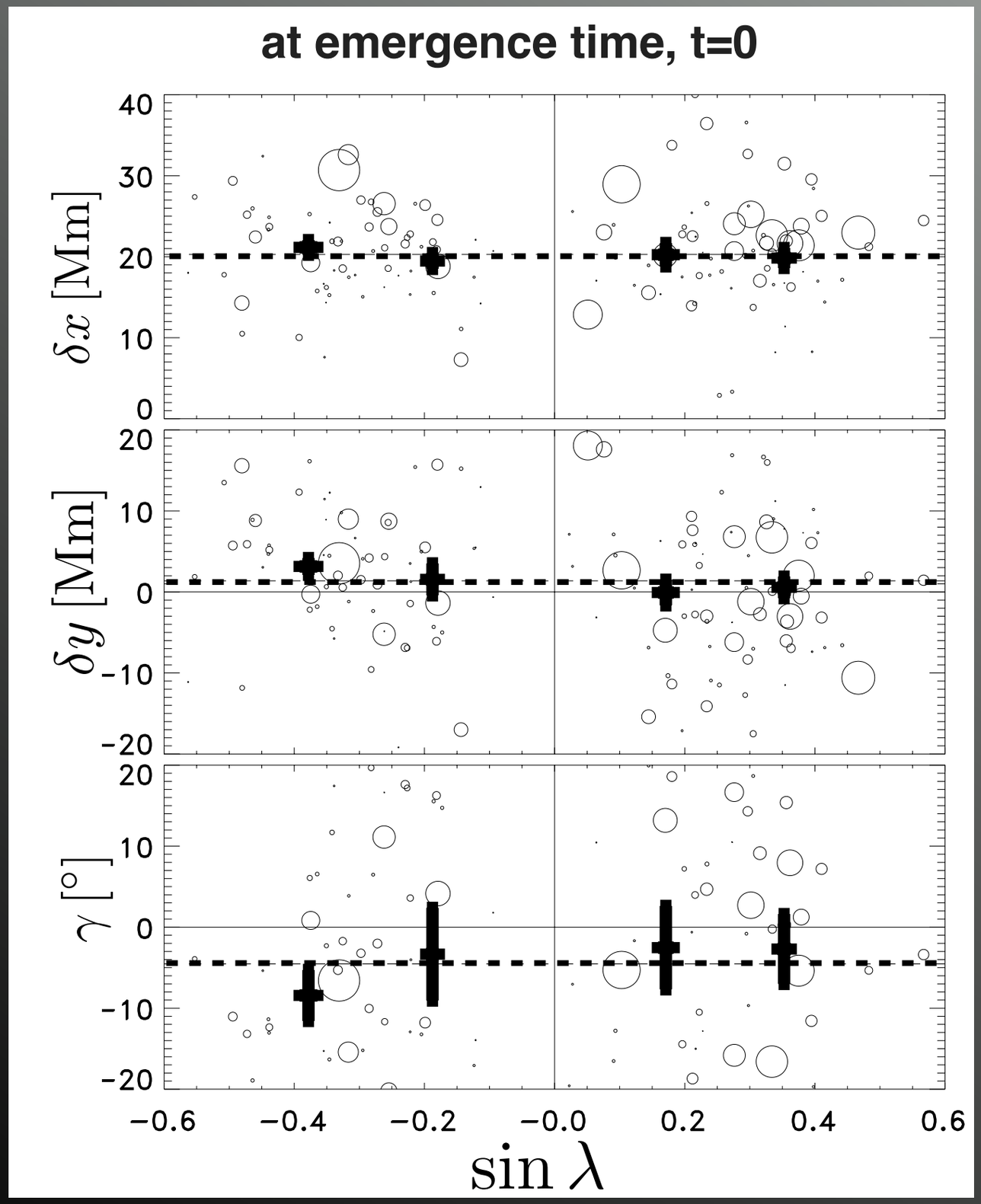
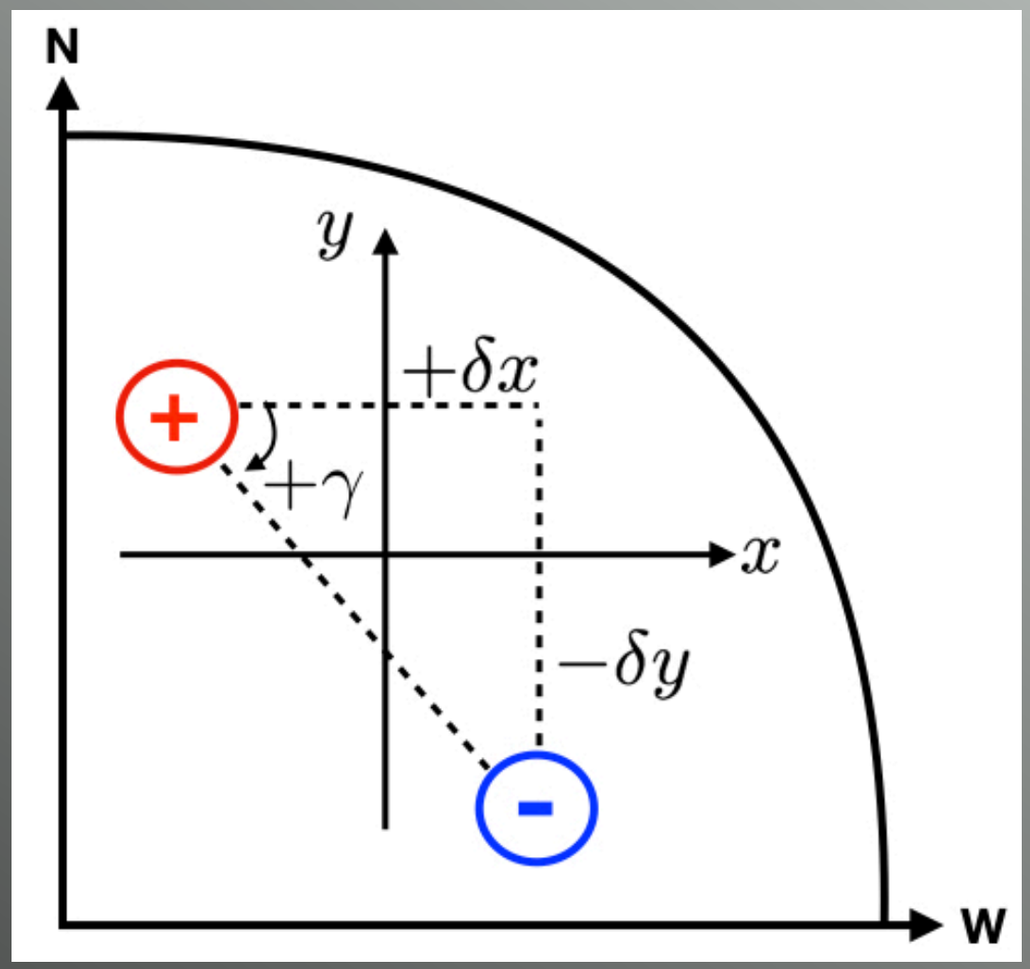
Average Tilt Angle Evolution





(excluded anti-Hale regions)

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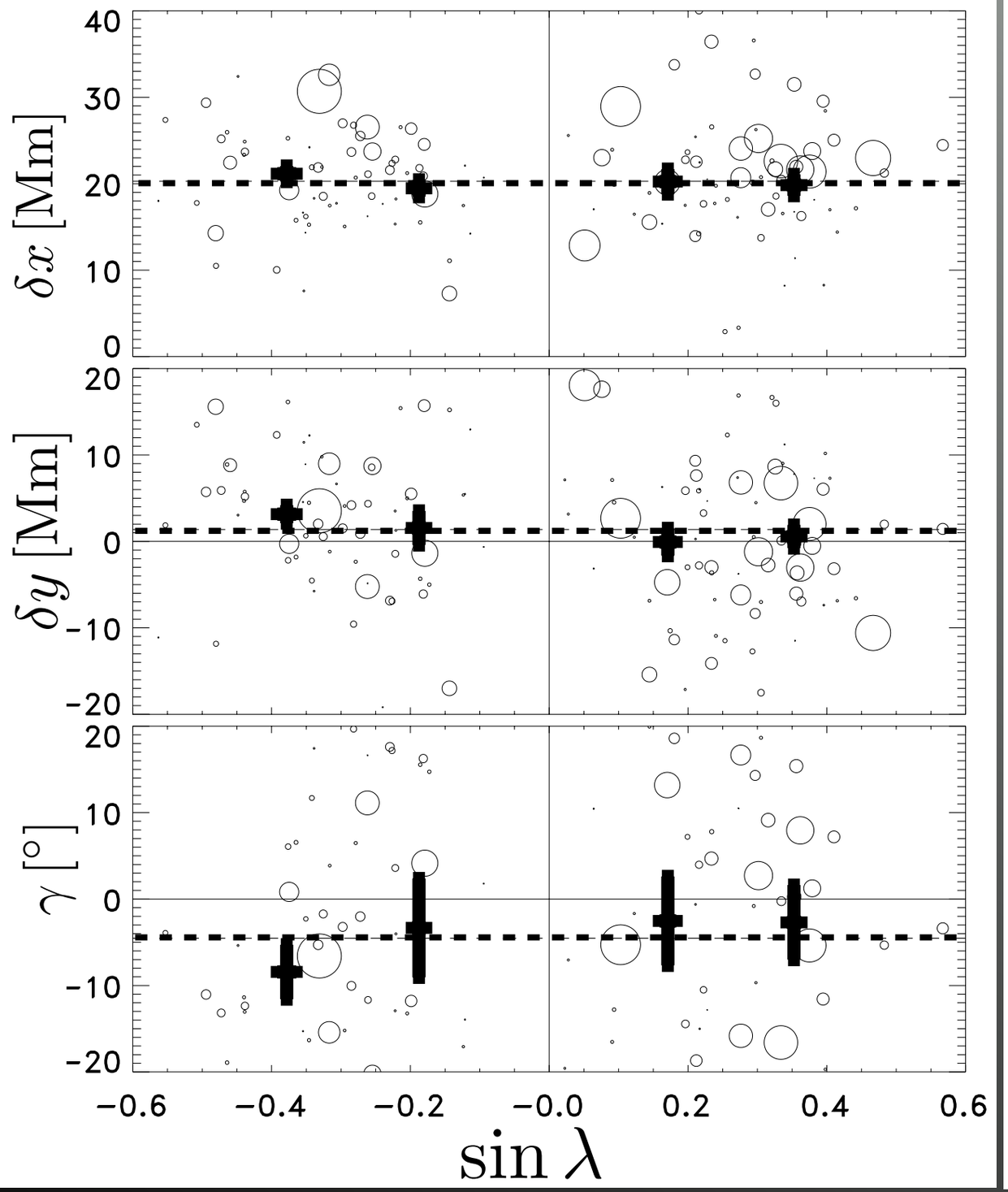
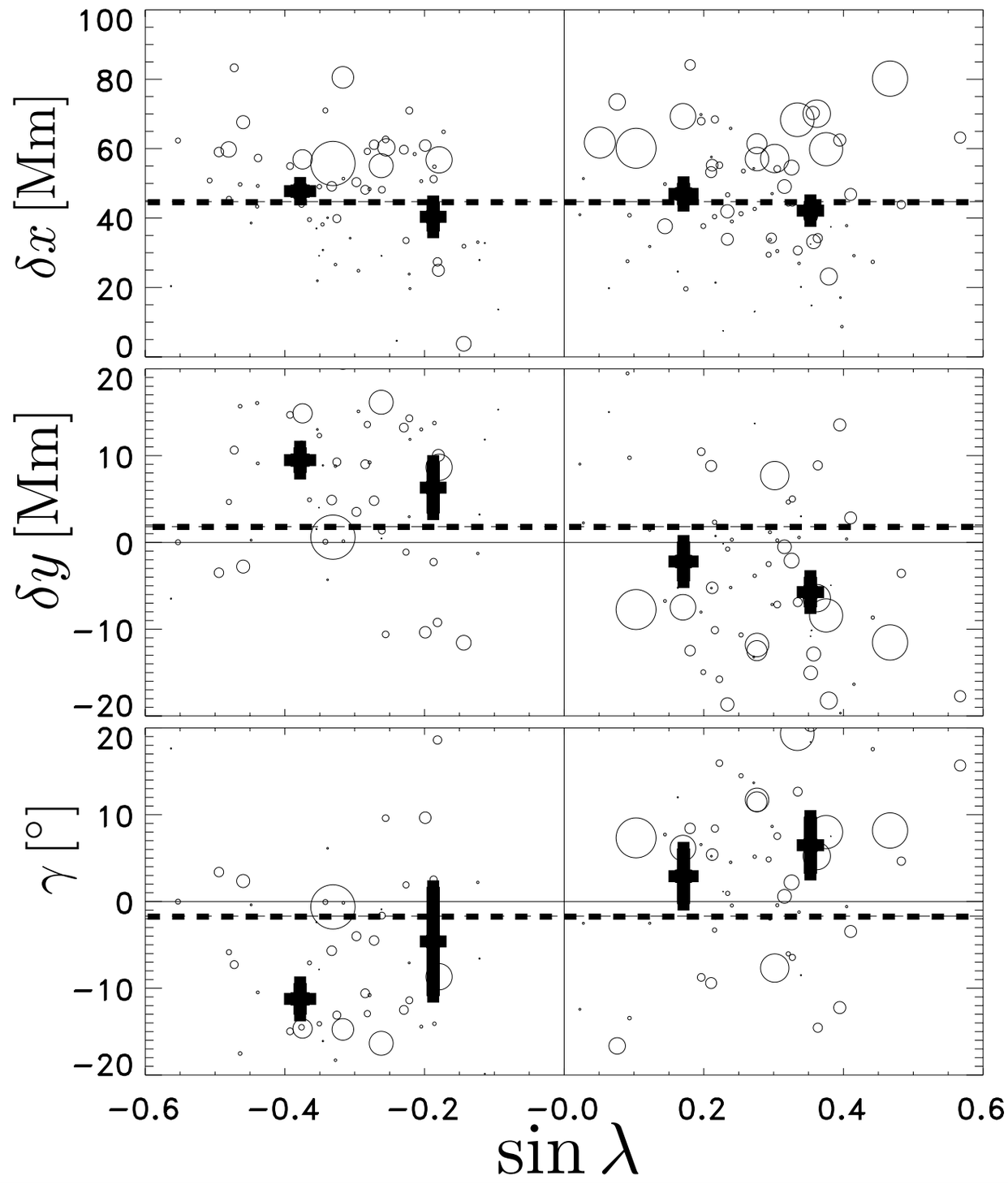
Average Tilt Angle Evolution

at emergence time, t=0



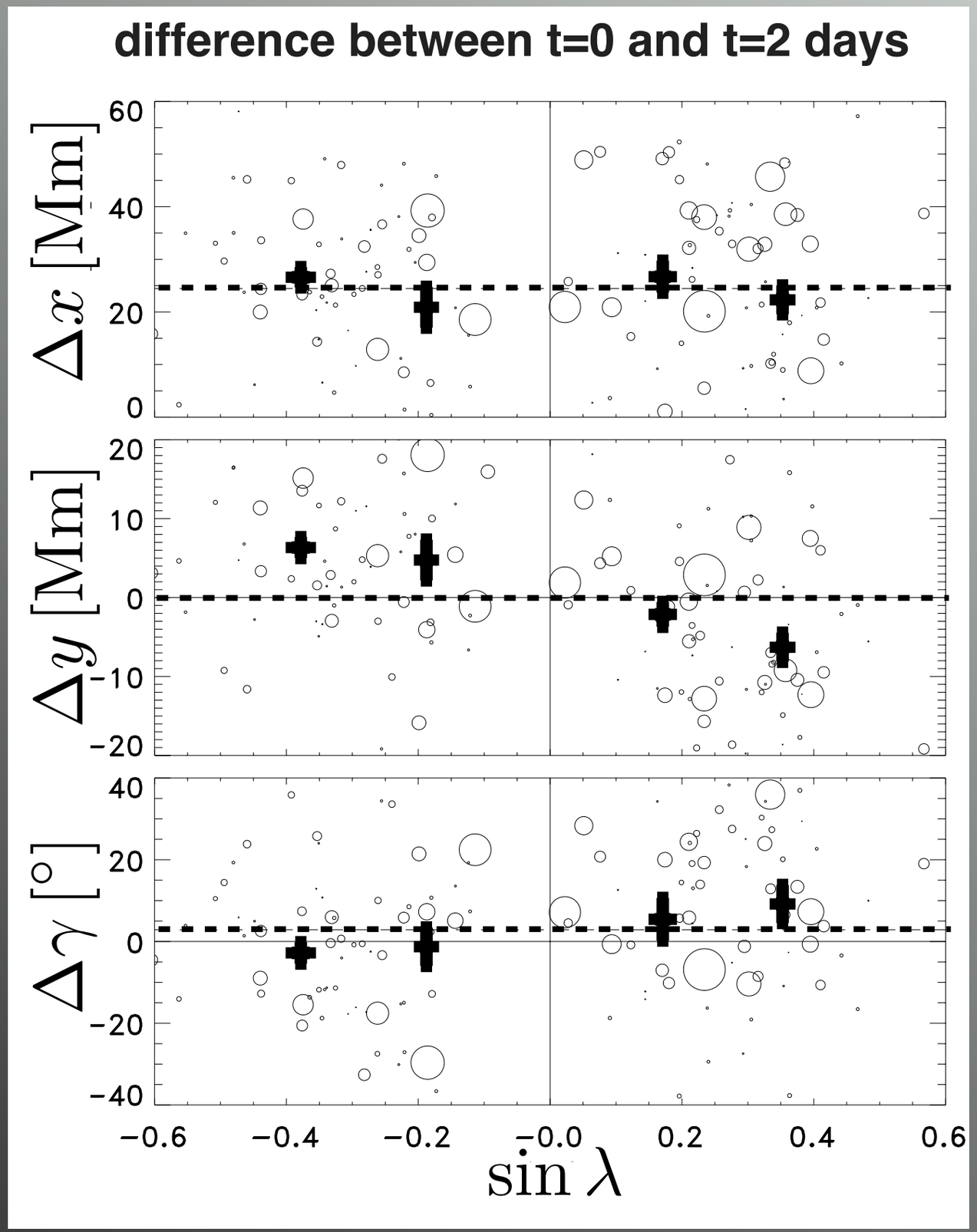
two days after emergence, t=2



Average Tilt Angle Evolution

No flux dependence on change in relative longitudinal or latitudinal separation, or tilt

Joy's Law due to relative latitudinal separation



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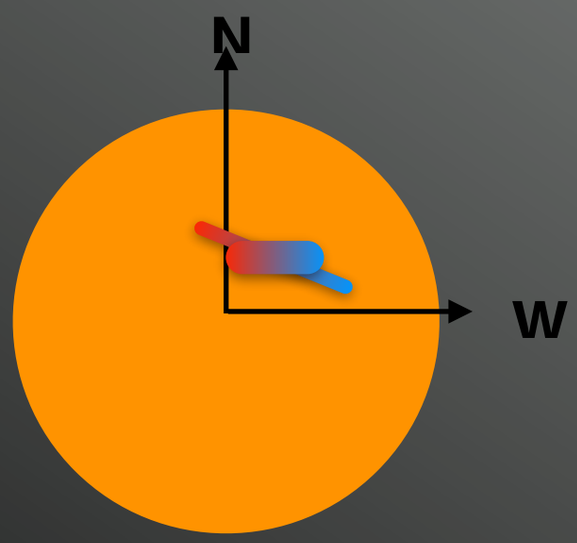
Constraints on Emergence

On average, polarities emerge E-W aligned, and then the tilt angle develops

We cannot exclude the possibility that the tilt angle is set as the flux tube rises through the deeper convection zone

- a writhe



Constraints on Emergence

On average, polarities emerge E-W aligned, and then the tilt angle develops

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- a writhe
- shredded by the near surface convection

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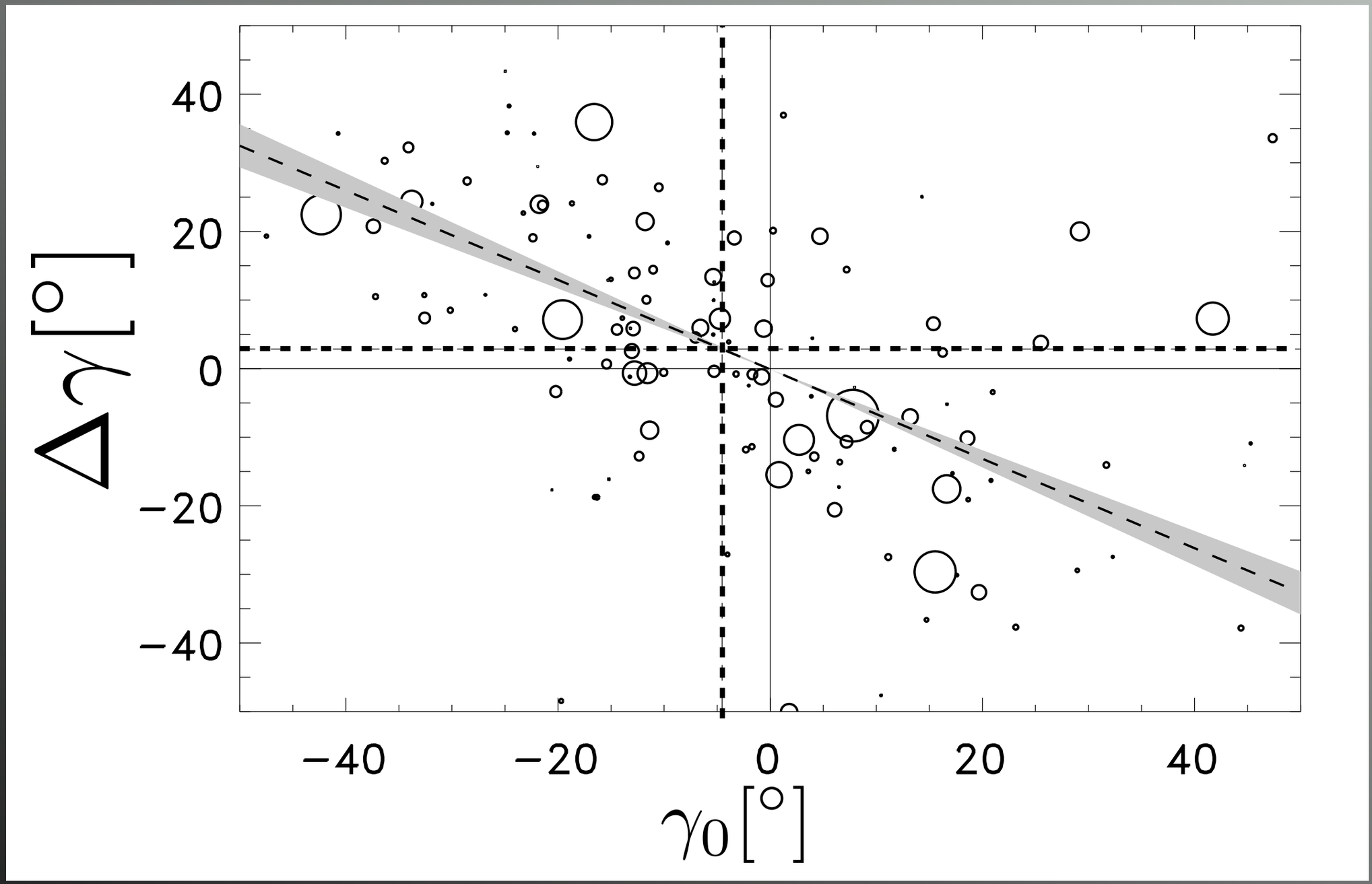
Tilt Angle Relaxation



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Tilt Angle Relaxation

Flux tube is tilted as it rises through the CZ

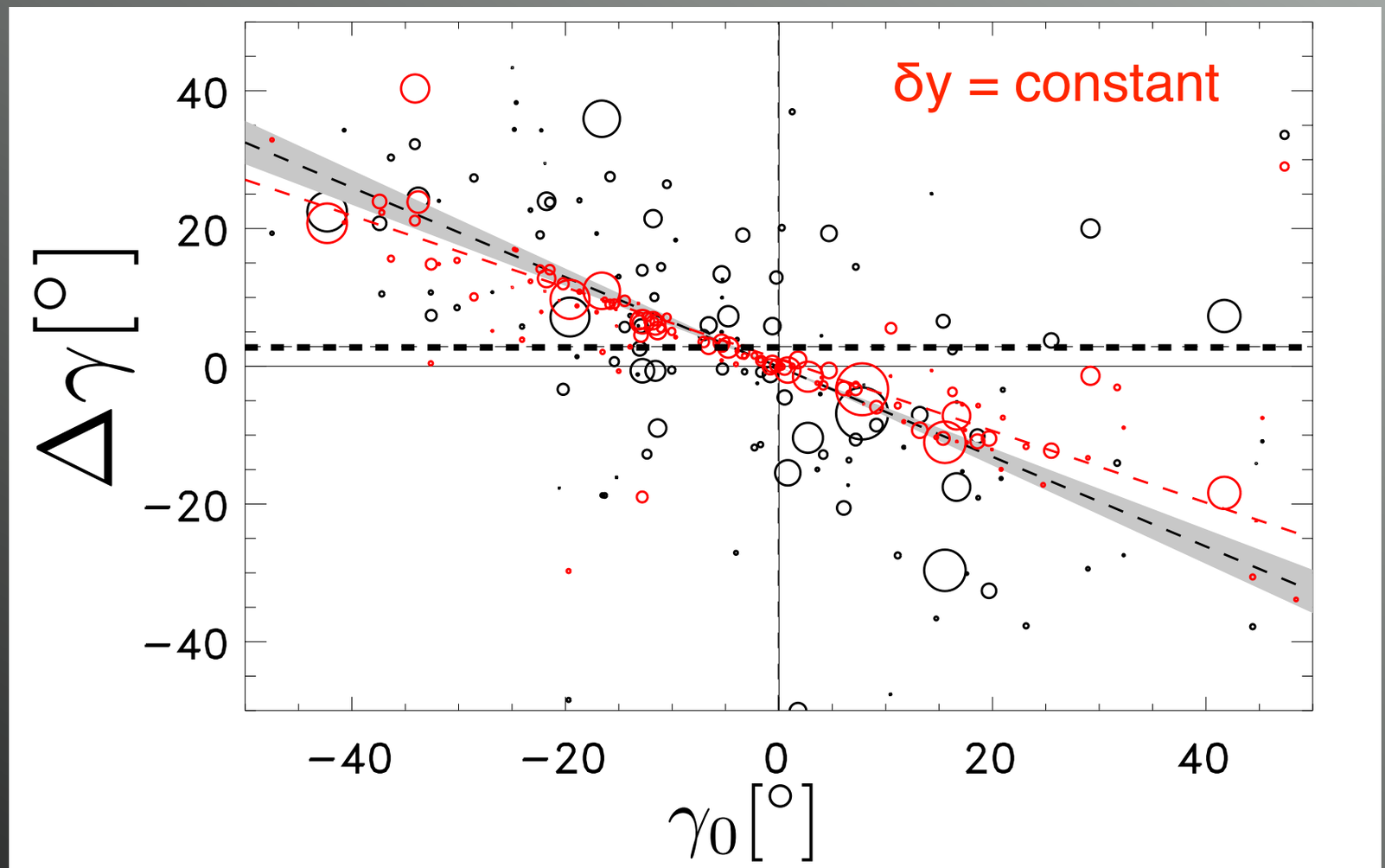
Shredded by near-surface convection → scatter

Magnetic tension forces the polarities to lie directly above the footpoints at the anchoring depth *Chen et al 2017*

→ deeply anchored flux tubes **?**

Longcope & Choudhuri 2002

‘Relaxation’ can be explained by the separation in the longitudinal direction



Passive and Active Components

Longitudinal separation
is flux dependent → active component
flux tube radius?

Change in longitudinal separation
is NOT flux dependent → passive component
same rise speed?

Latitudinal separation and change
is latitude dependent → Coriolis force
is not flux dependent → passive component

What E-W flow is the Coriolis force acting on?

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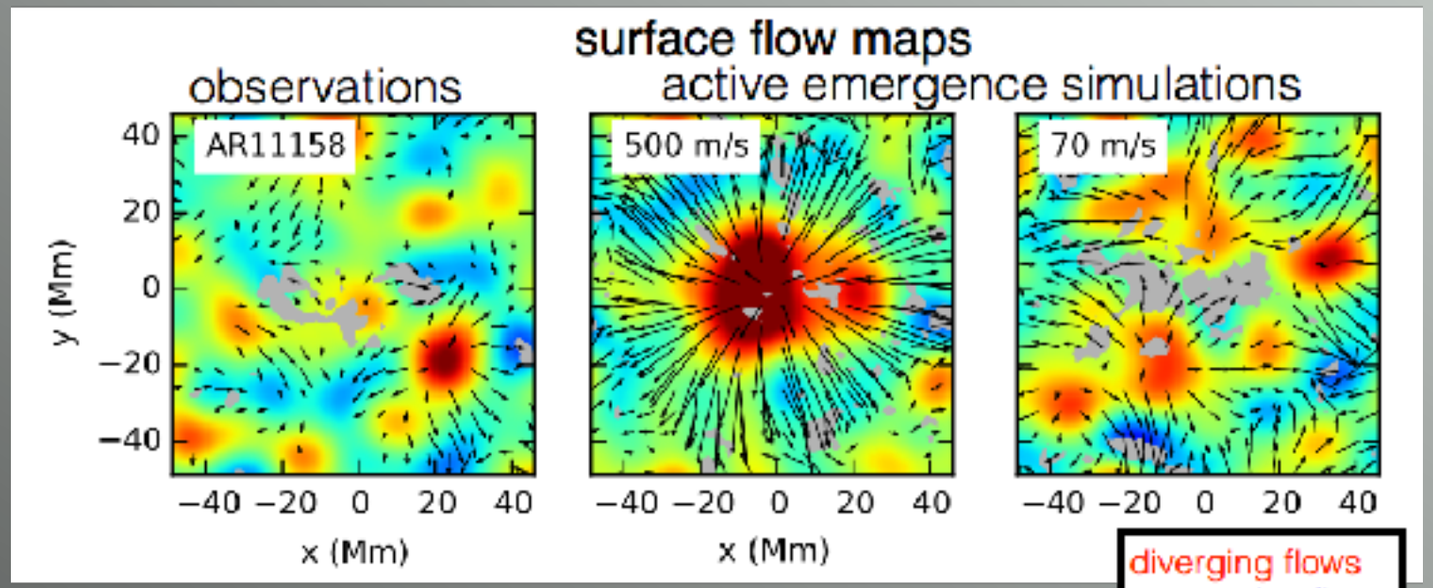
Convection is Important

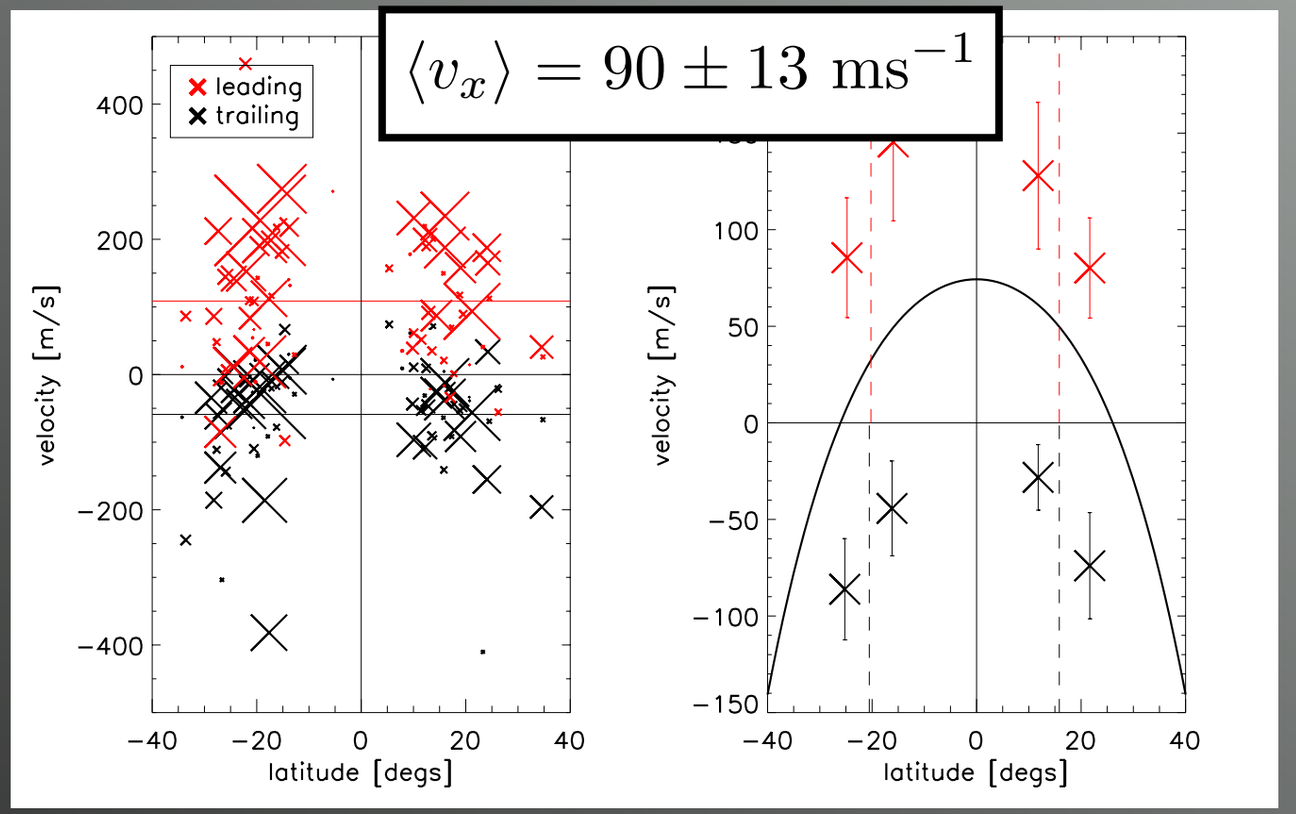
Flux tubes have rise speeds on the order of the convective velocities

Birch et al 2016



Polarities separate anti-symmetrically in the East-West direction in the first day after emergence

Schunker et al 2016



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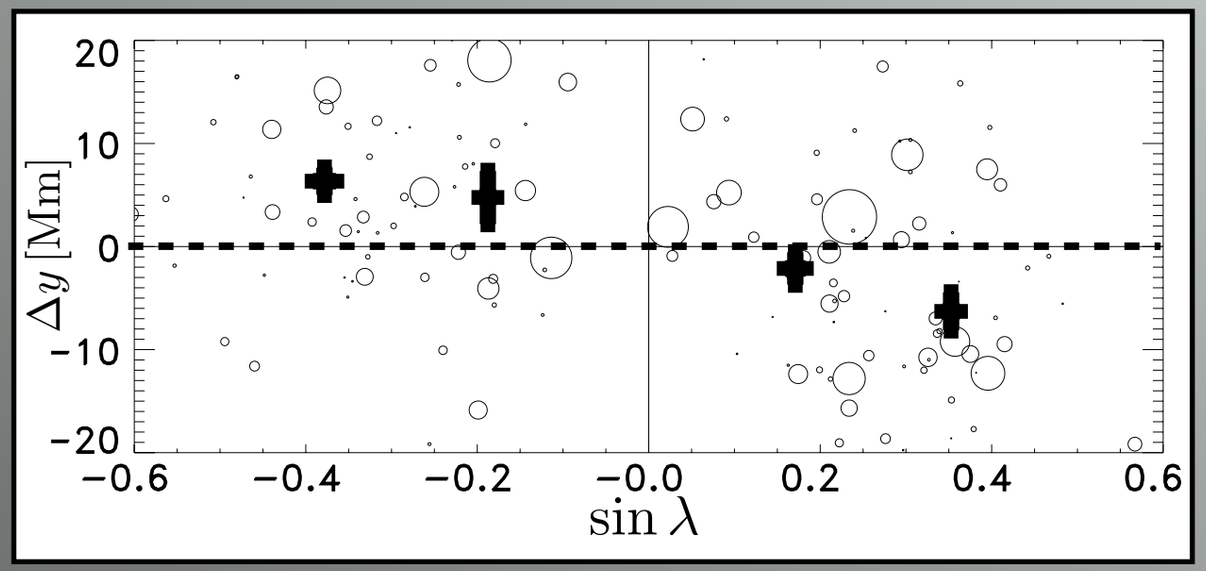
Tilt Angle Evolution

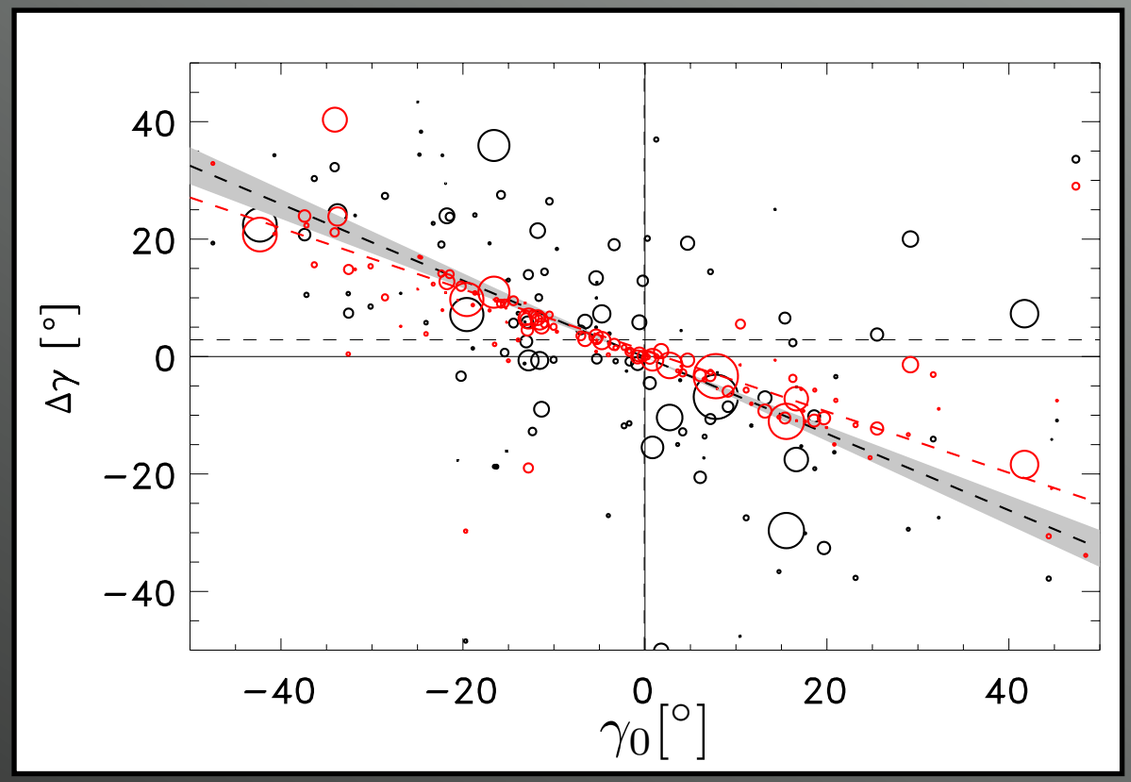
Joy's Law is due to the latitudinal change in separation: not a constant tilt angle

Schunker et al in prep.



Tilt angle 'relaxation' can be largely explained by the longitudinal separation

Schunker et al in prep.



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Towards Tighter Constraints

Is the Coriolis force responsible for tilt angle?
What East-West flow is it acting on?

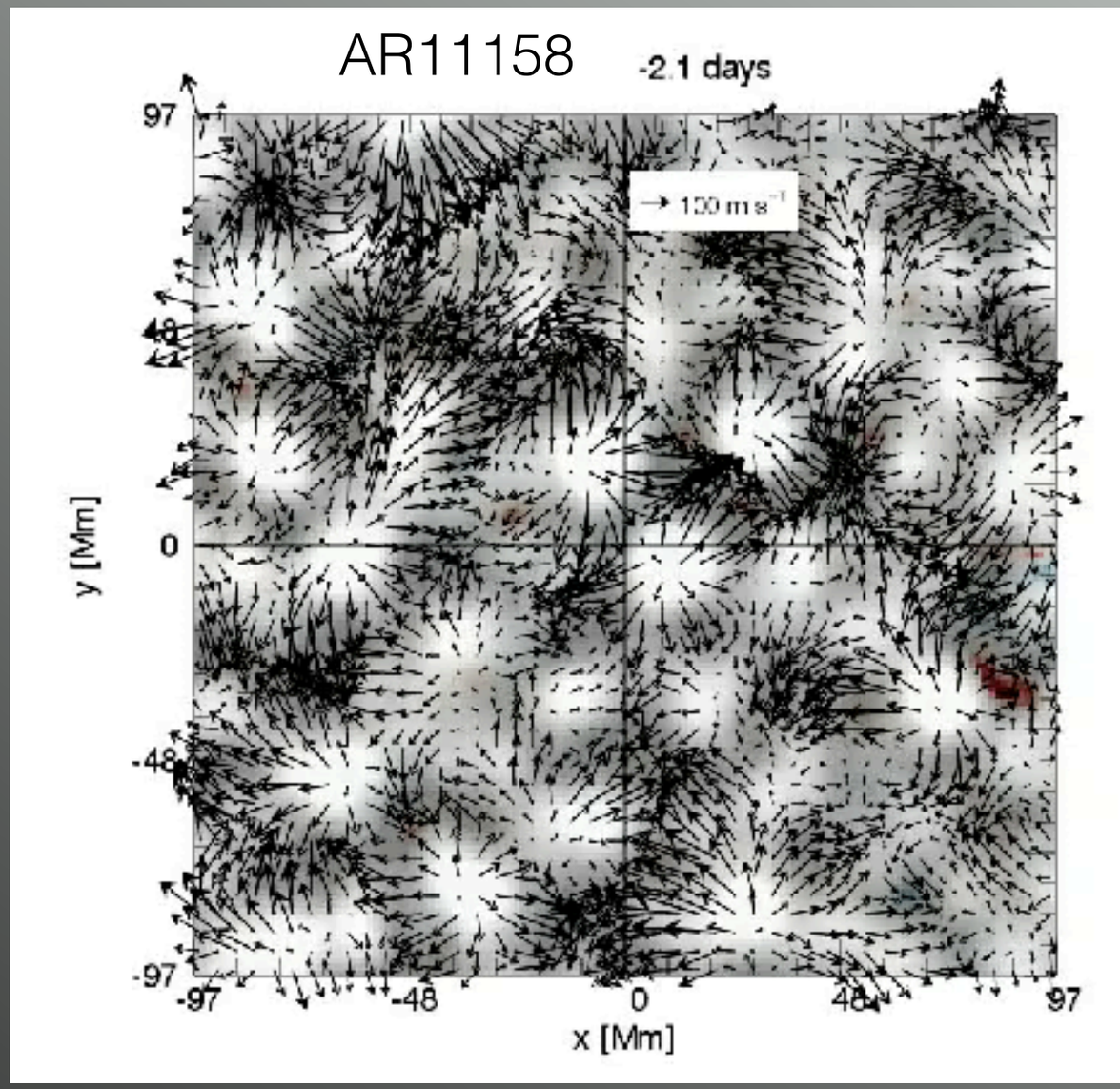
Motion of the polarities in relation to the flows as a function of *time* and *depth*

Twist of flux tubes

Quantitative comparisons to other numerical models (e.g. deeper; active regions formed by convection

e.g. Cheung et al 2010; Stein 2008)

+ rotation



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