Twisted currents of coronal loops in 3D MHD simulations

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Contributed Talk

1. Fundamental physical processes and modeling

Twisted currents of coronal loops in 3D MHD simulations

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The magnetic field in the low plasma-beta solar corona is often assumed to be nonlinear force-free. We find that this assumption is not necessarily fulfilled in extreme UV bright loop structures. In a 3D numerical MHD model of a corona above an emerging active region a coronal loop forms self-consistently as a consequence of the emerging magnetic flux and the horizontal motions at the surface. We find that the current along the emerging loop changes its sign from being antiparallel to parallel to the magnetic field from one leg to the other. This is caused by the inclination of the loop together with the footpoint motion. Around the loop, the currents form a complex non-force-free helical structure. This is directly related to a bipolar current structure at the loop footpoints at the base of the corona and a local reduction of the background magnetic field (i.e., outside the loop) caused by the plasma flow into and along the loop. Furthermore, the locally reduced magnetic pressure in the loop allows the loop to sustain a higher density, which is crucial for the emission in extreme UV. We find that twisted currents quantified in terms of current helicity seems to coincide with the hot and bright UV loops, indicating a direct connection between current helicity and to the heating process. This might imply also a link to the underlying dynamo mechanism, where current helicity can be produced and transported to the surface. To investigate the role of current helicity further, we, therefore, also present some results of 3D MHD simulations of the solar corona, where we enhance the current helicity at the photosphere and study its response as seen in the corona.

Twisted currents of coronal loops in 3D MHD simulations

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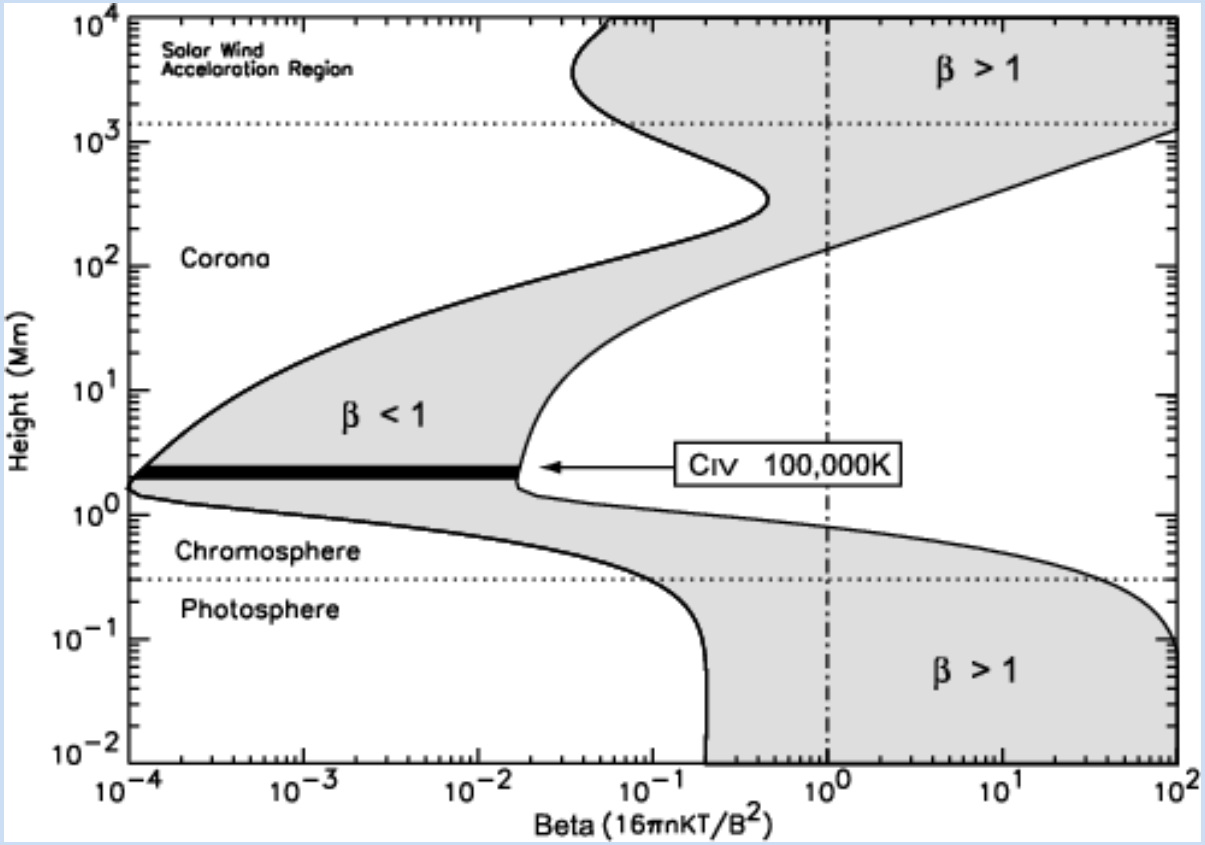
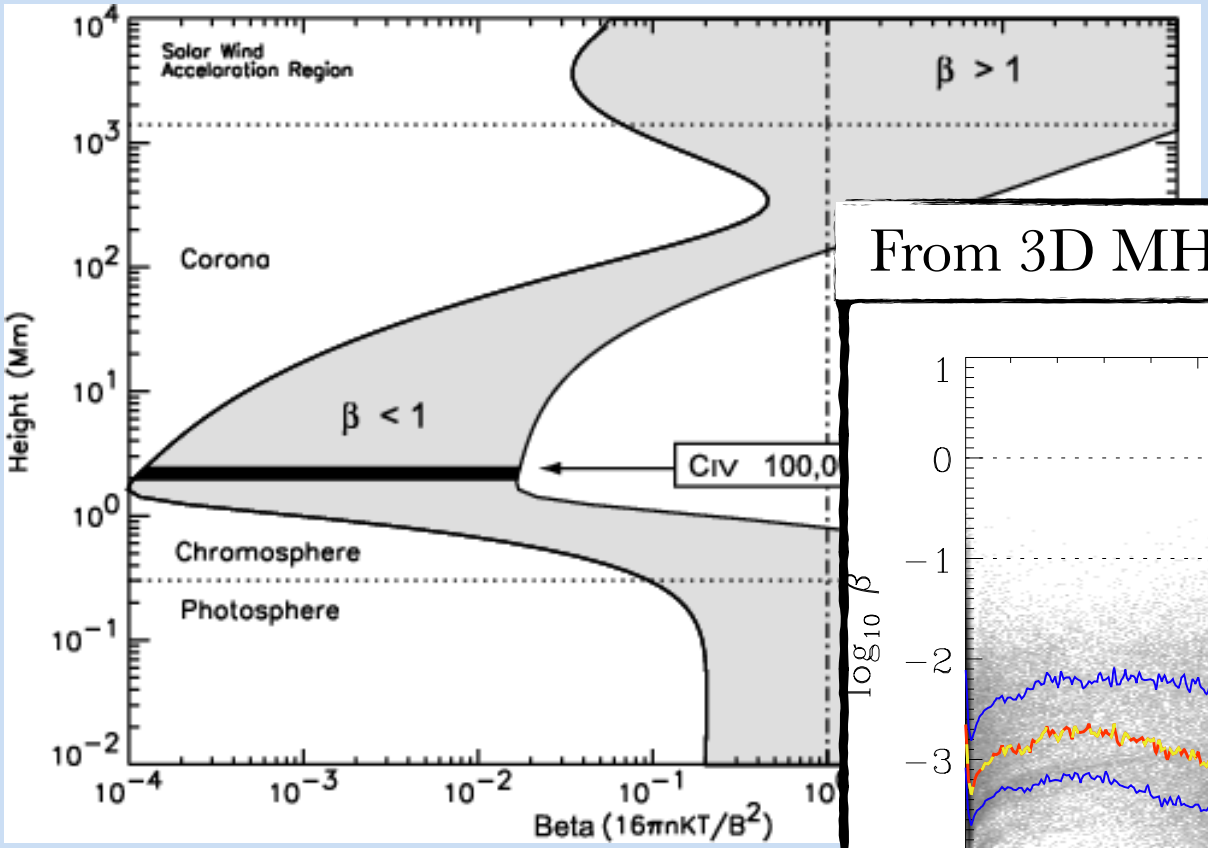
Force-free solar corona

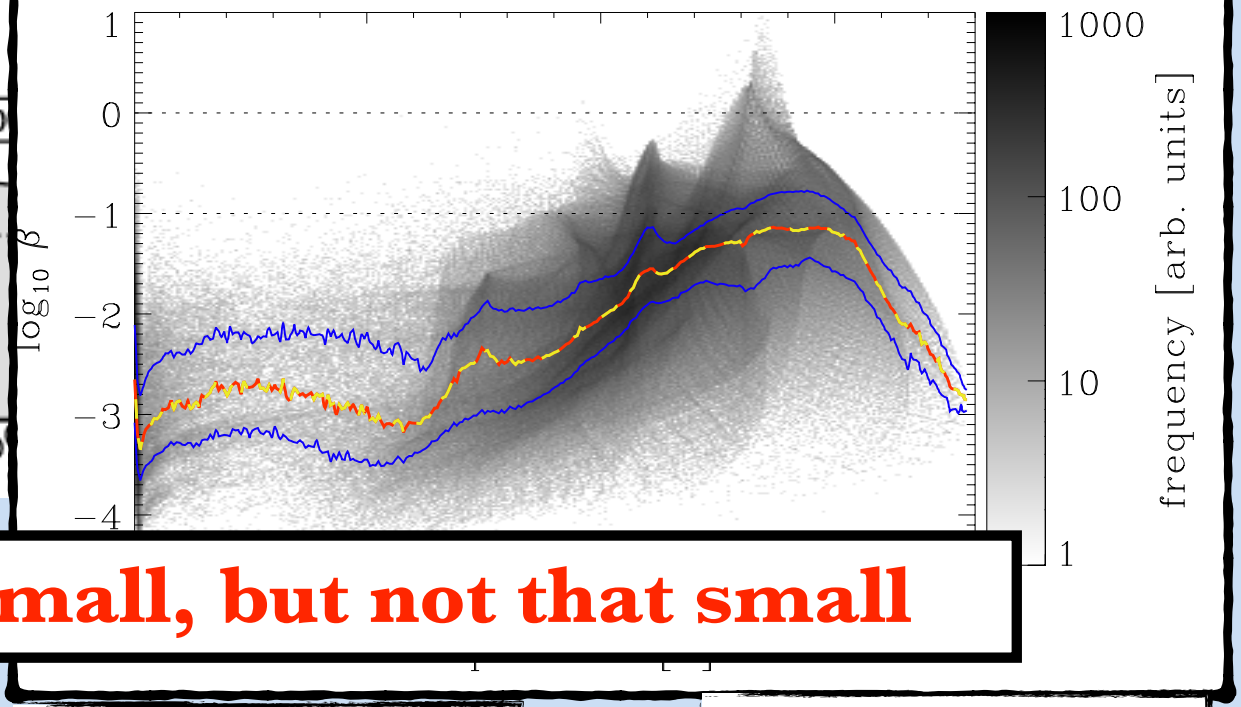


Garry 2001

Force-free solar corona



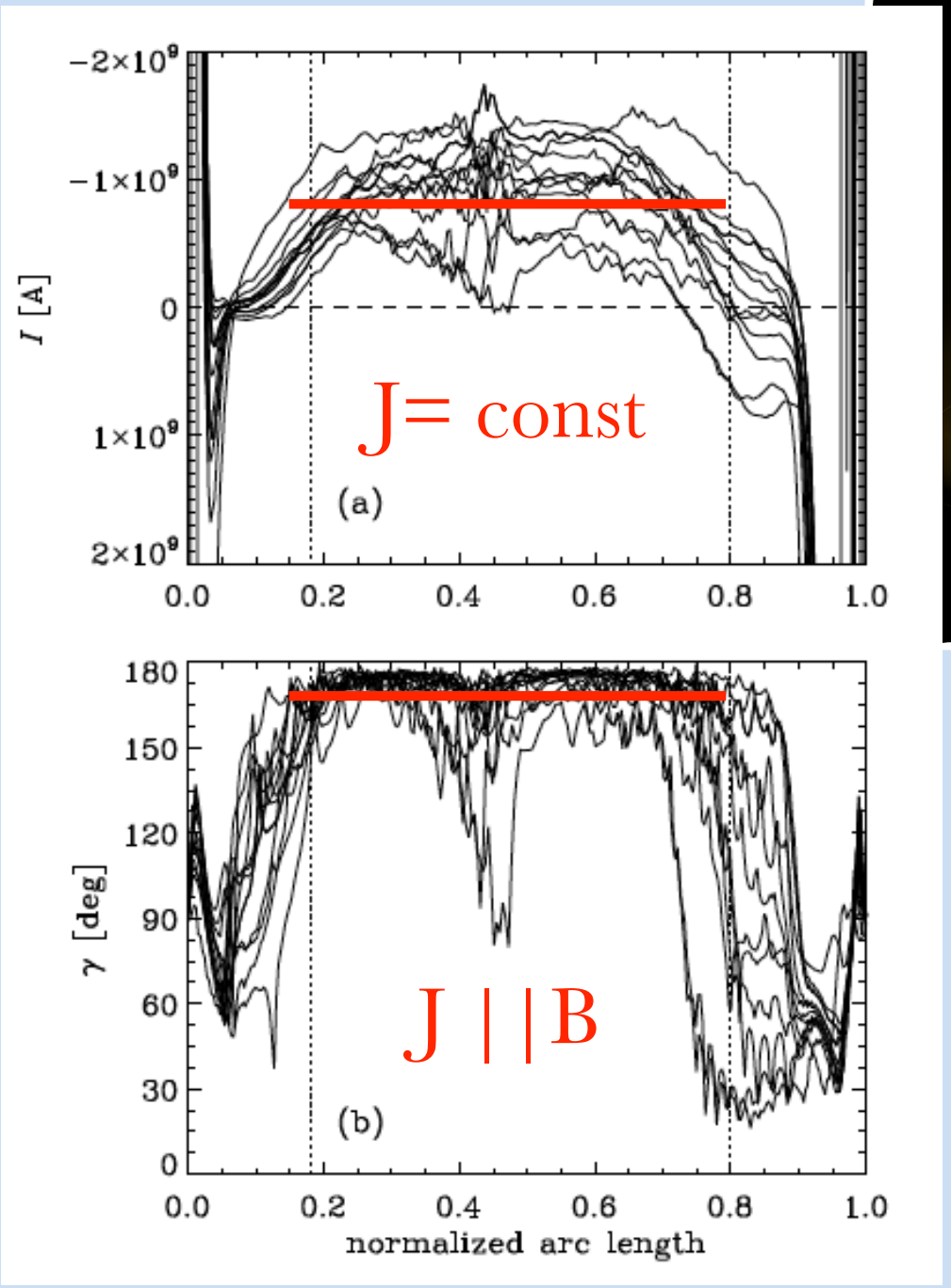
From 3D MHD model quasi-stationary corona

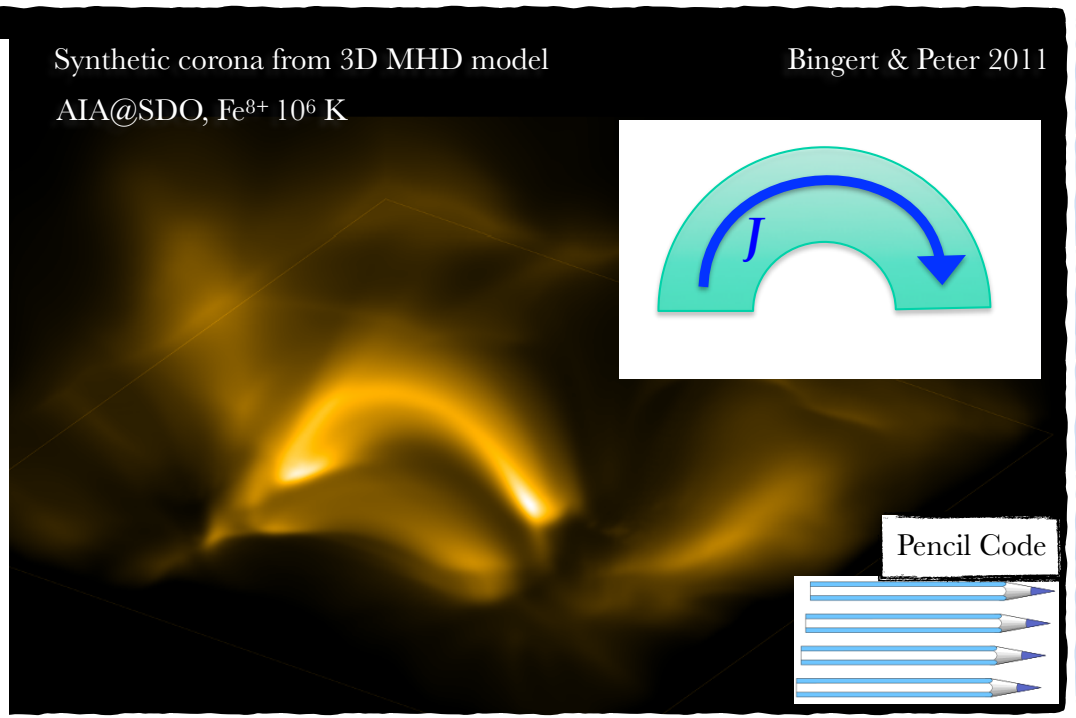


Plasma beta small, but not that small

Peter, Warnecke et al. 2015

From data of Bingert & Peter 2011





Bottom boundary

- Vertical magnetic field
- Prescribed velocity field

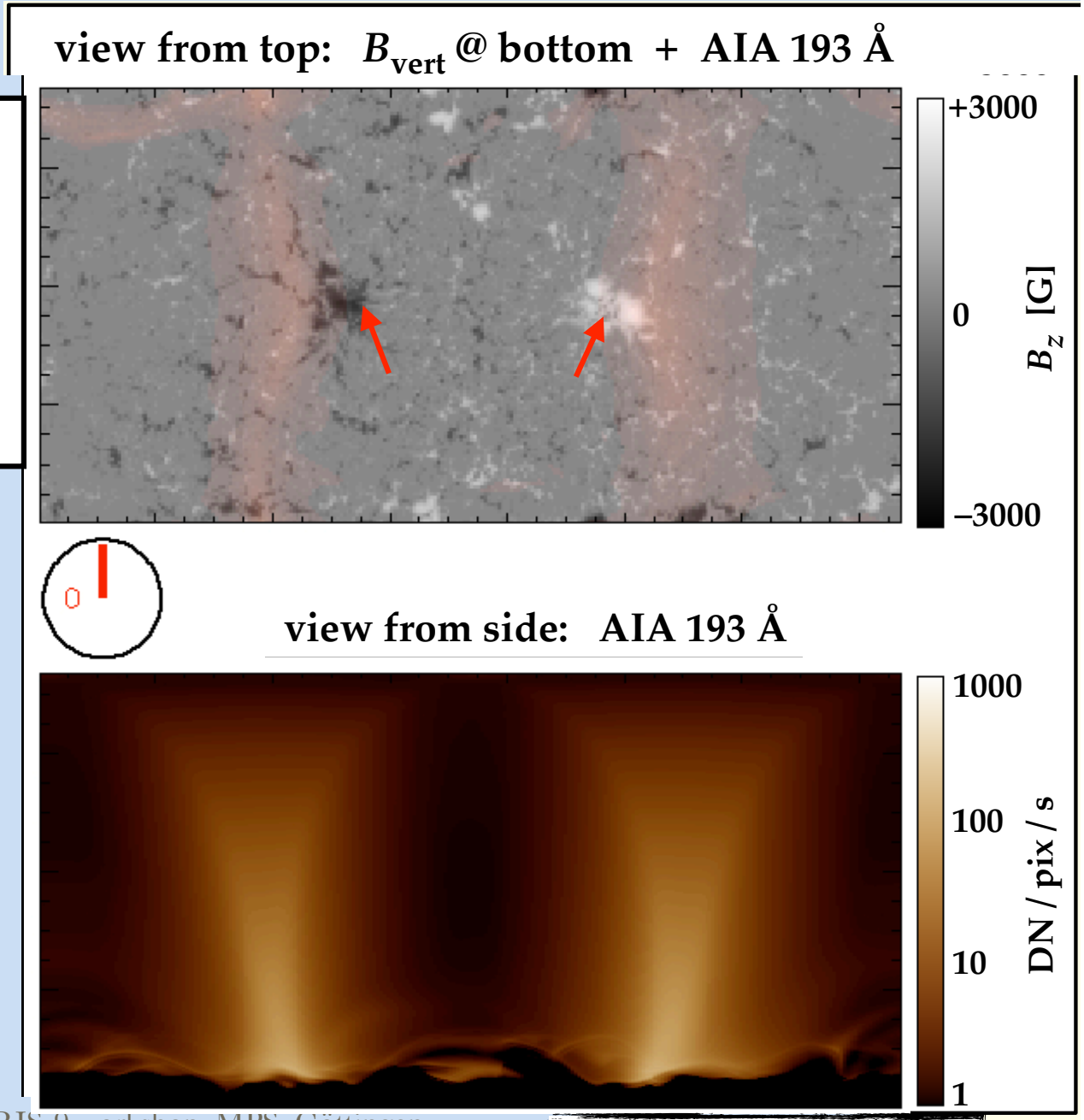
- Spitzer heat conductivity, along B

In quasi-stationary loops, J and B aligned

Corona above an emerging active region

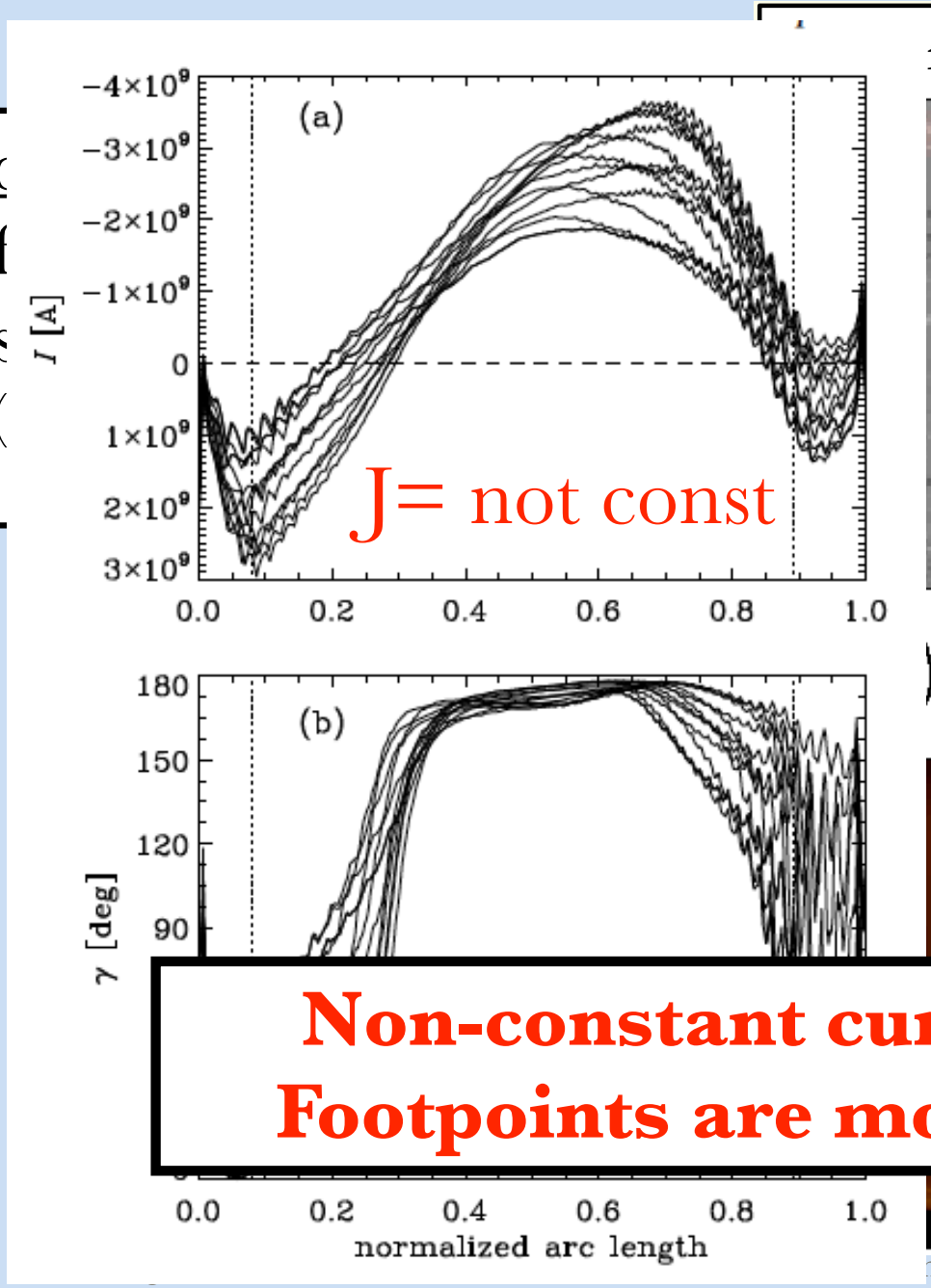
Bottom boundary

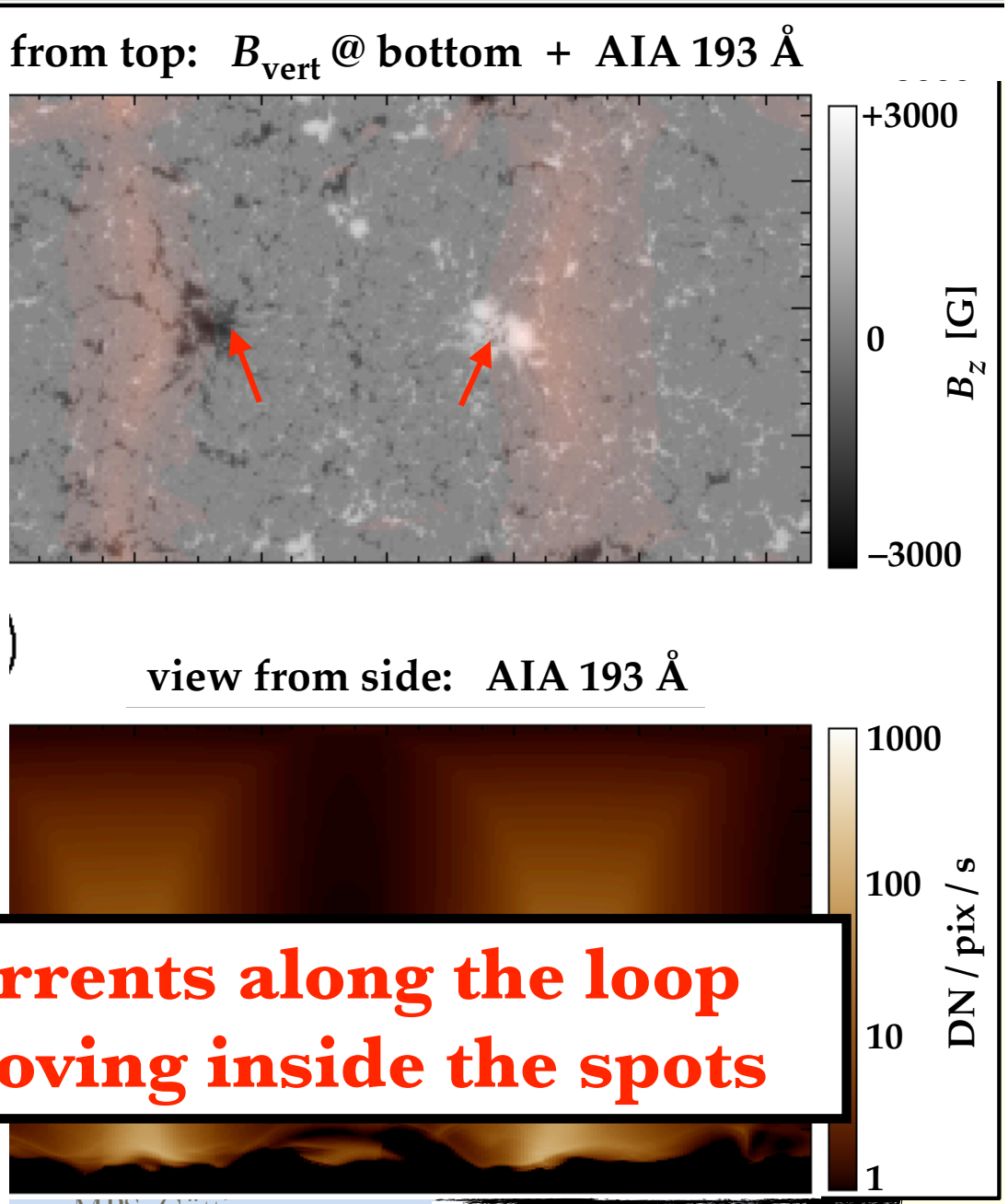
- flux emergence simulation
  (Cheung & Rempel 2014)



Chen et al. 2014, 2015

Corona above an emerging active region

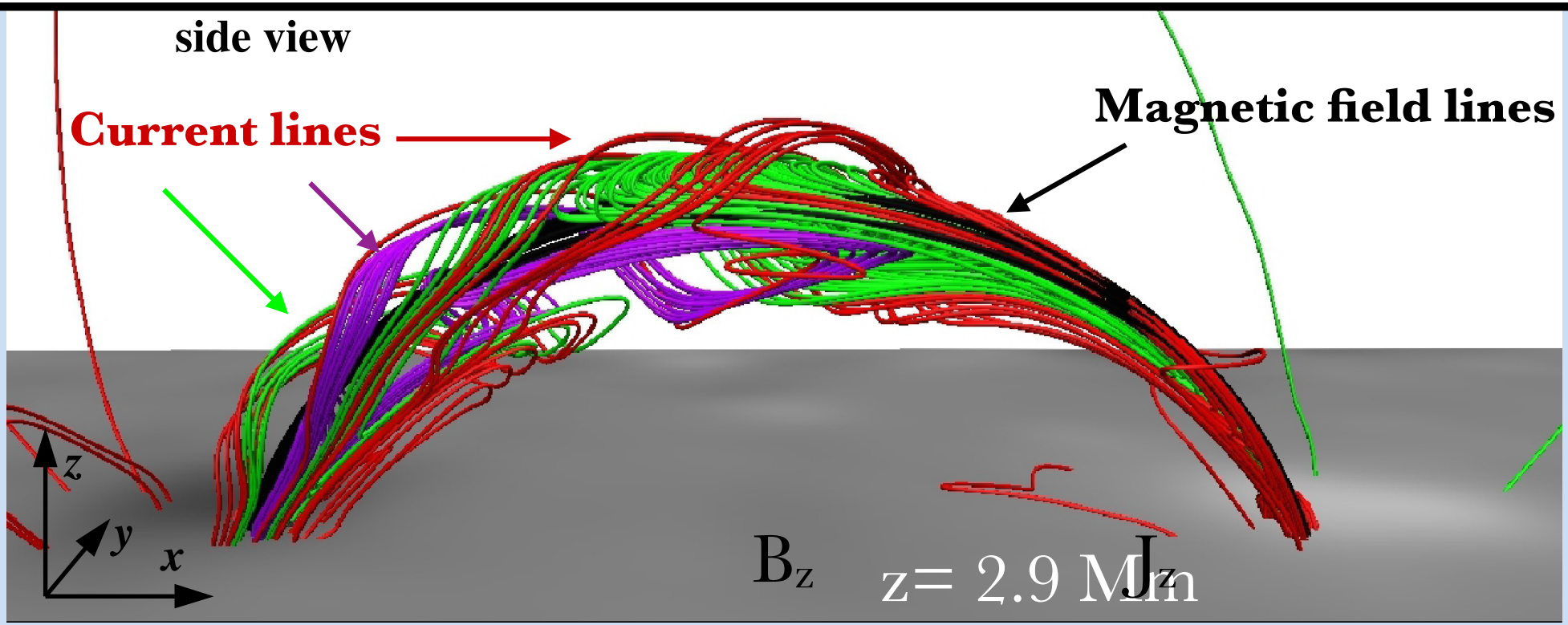




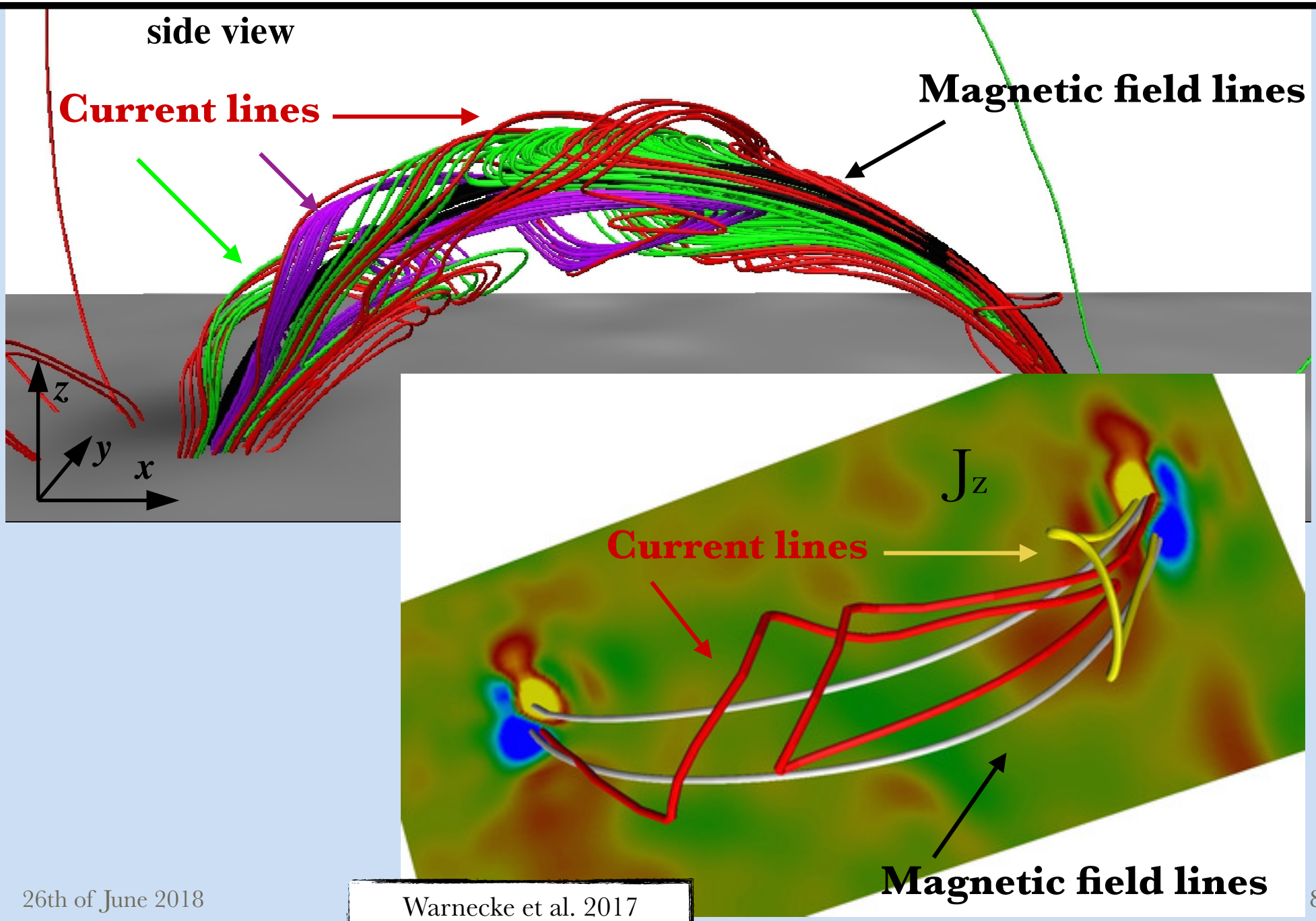
Non-constant currents along the loop
Footpoints are moving inside the spots

Chen et al. 2014, 2015

Current structure in the loop

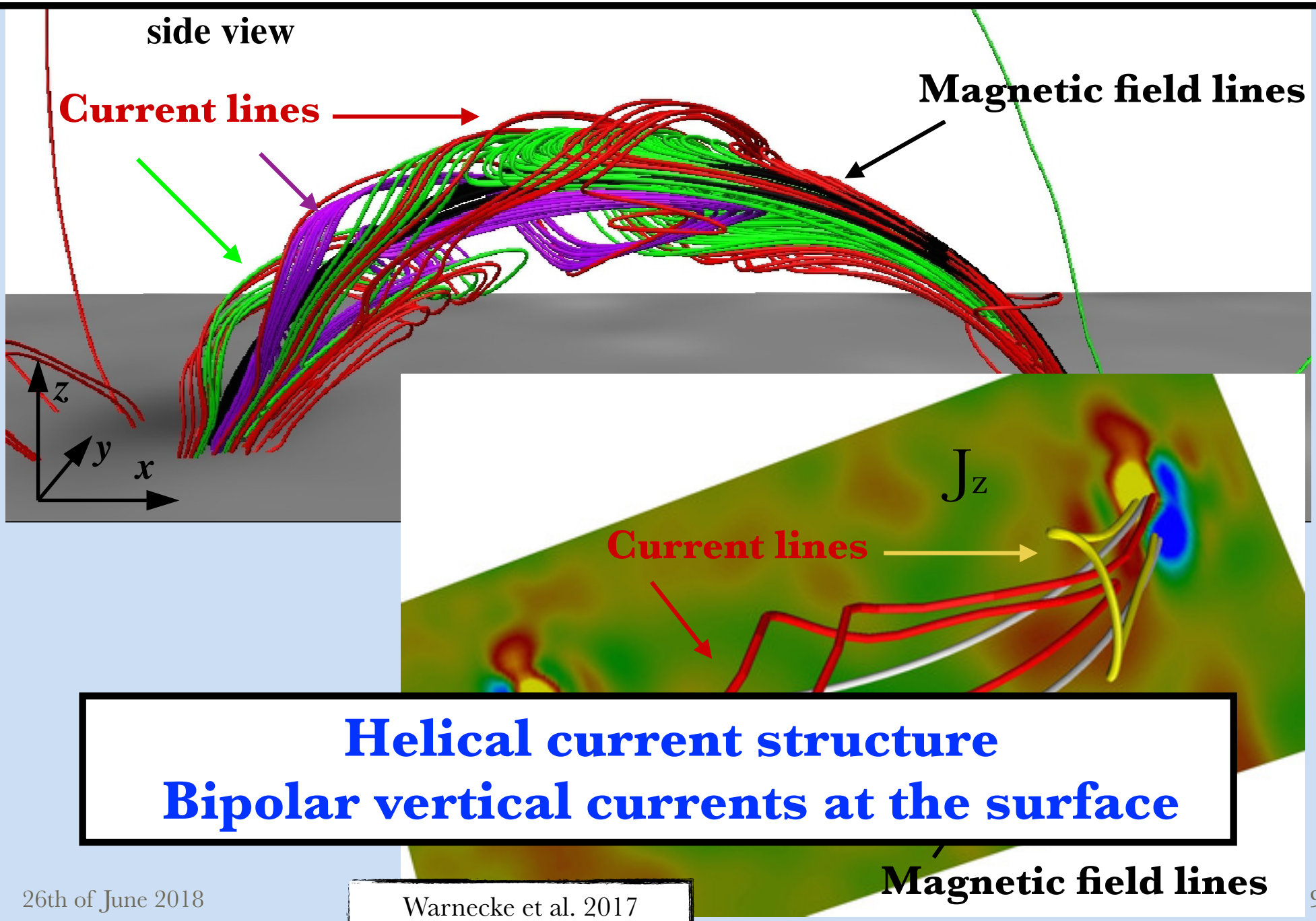


Current structure in the loop



Warnecke et al. 2017

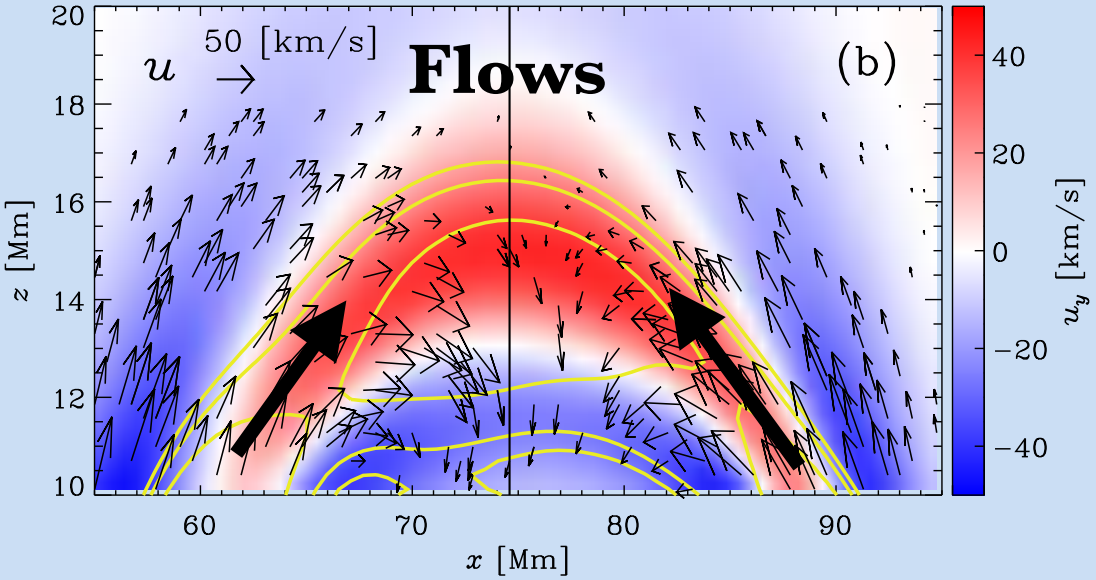
Current structure in the loop

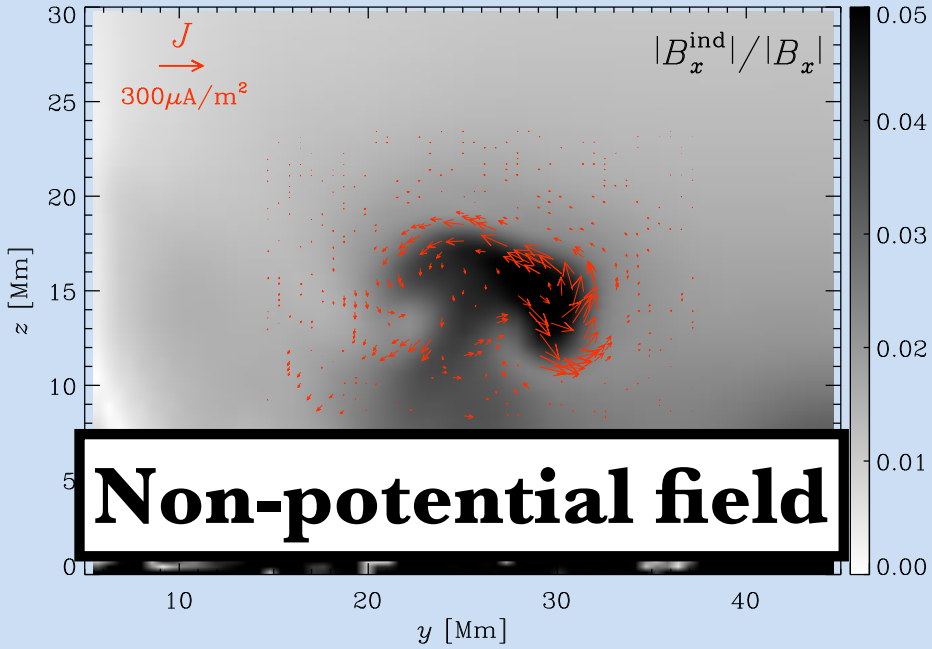


Helical current structure
Bipolar vertical currents at the surface

Warnecke et al. 2017

Plasma flows into the loop

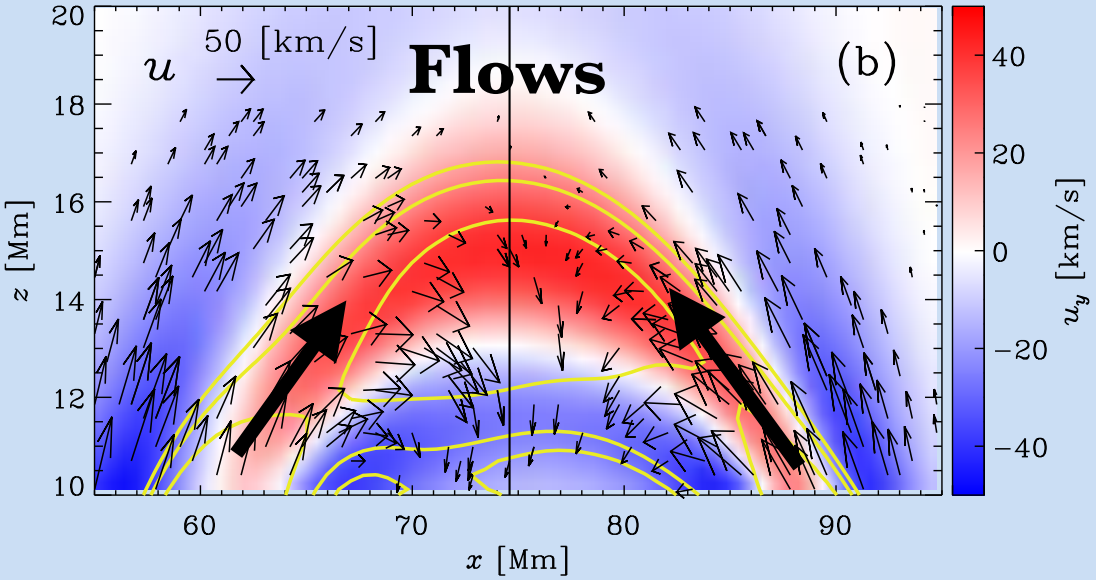




- Ohmic heating in the loop drives upflows along the legs
- Changes the magnetic field structure
- Non-pontential magnetic field

- Helical current structure

Plasma flows into the loop

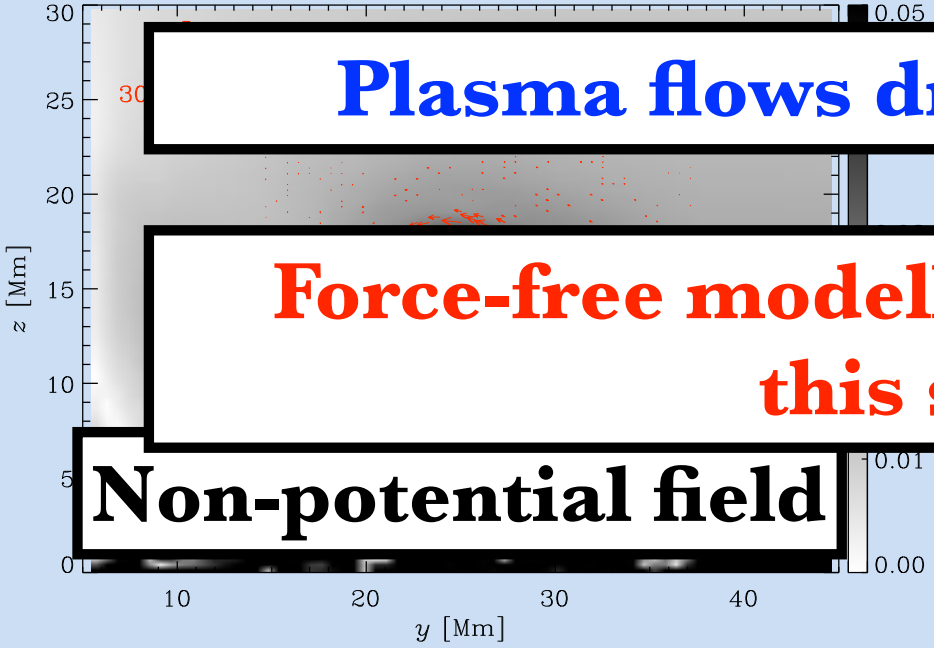


- Ohmic heating in the loop drives upflows along the legs
- Changes the magnetic field structure
- Non-pontential magnetic field

Plasma flows drive helical currents

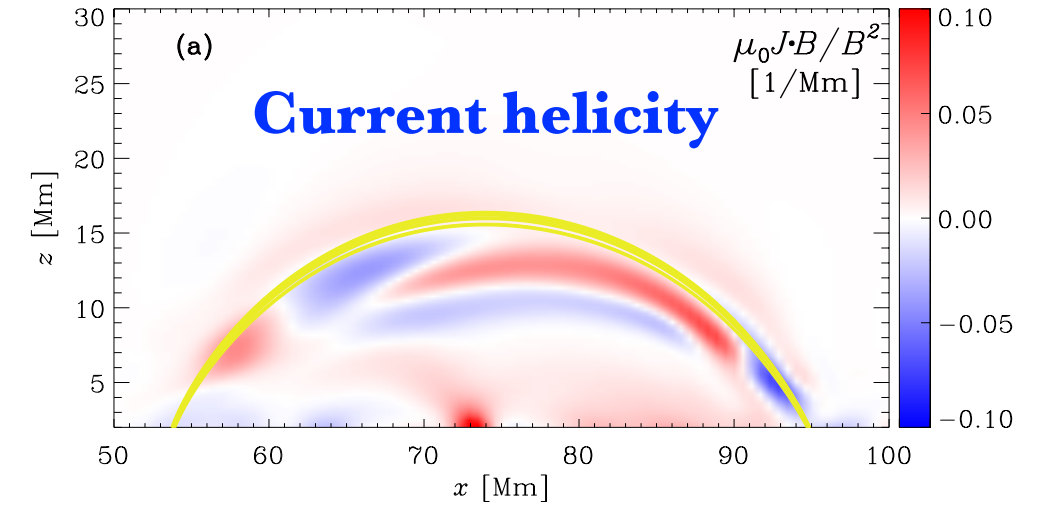
- Helical current structure

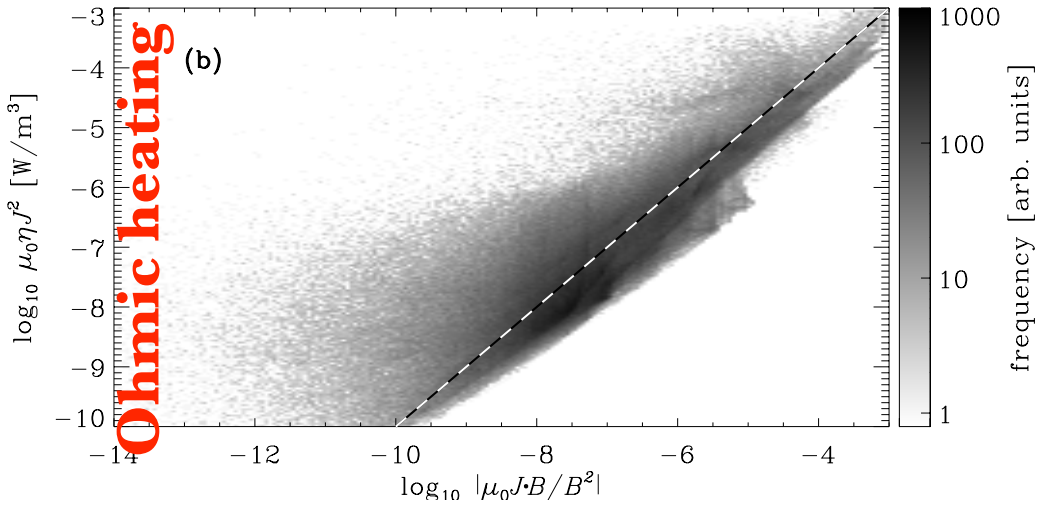
Force-free modelling cannot described this structure



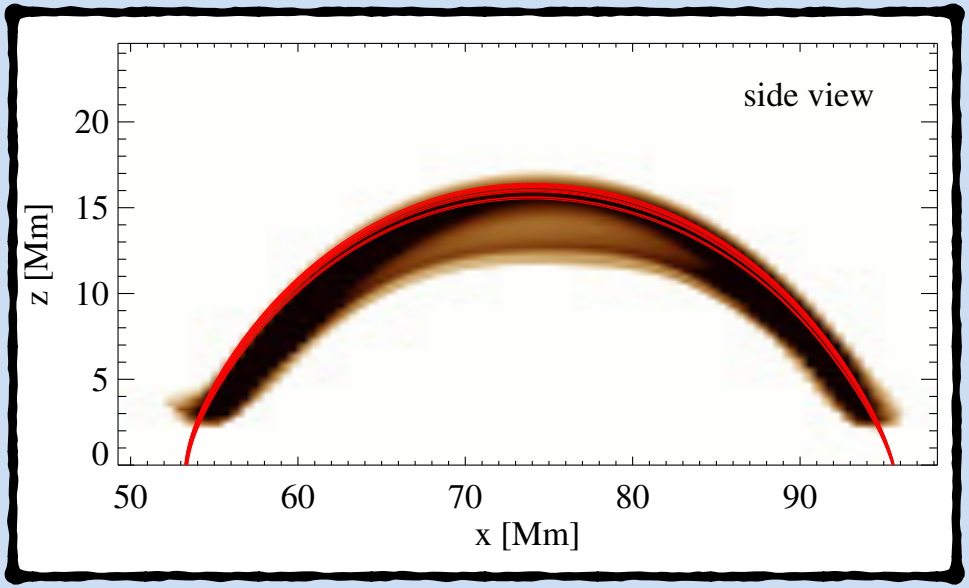
Non-potential field

Current helicity in the loop



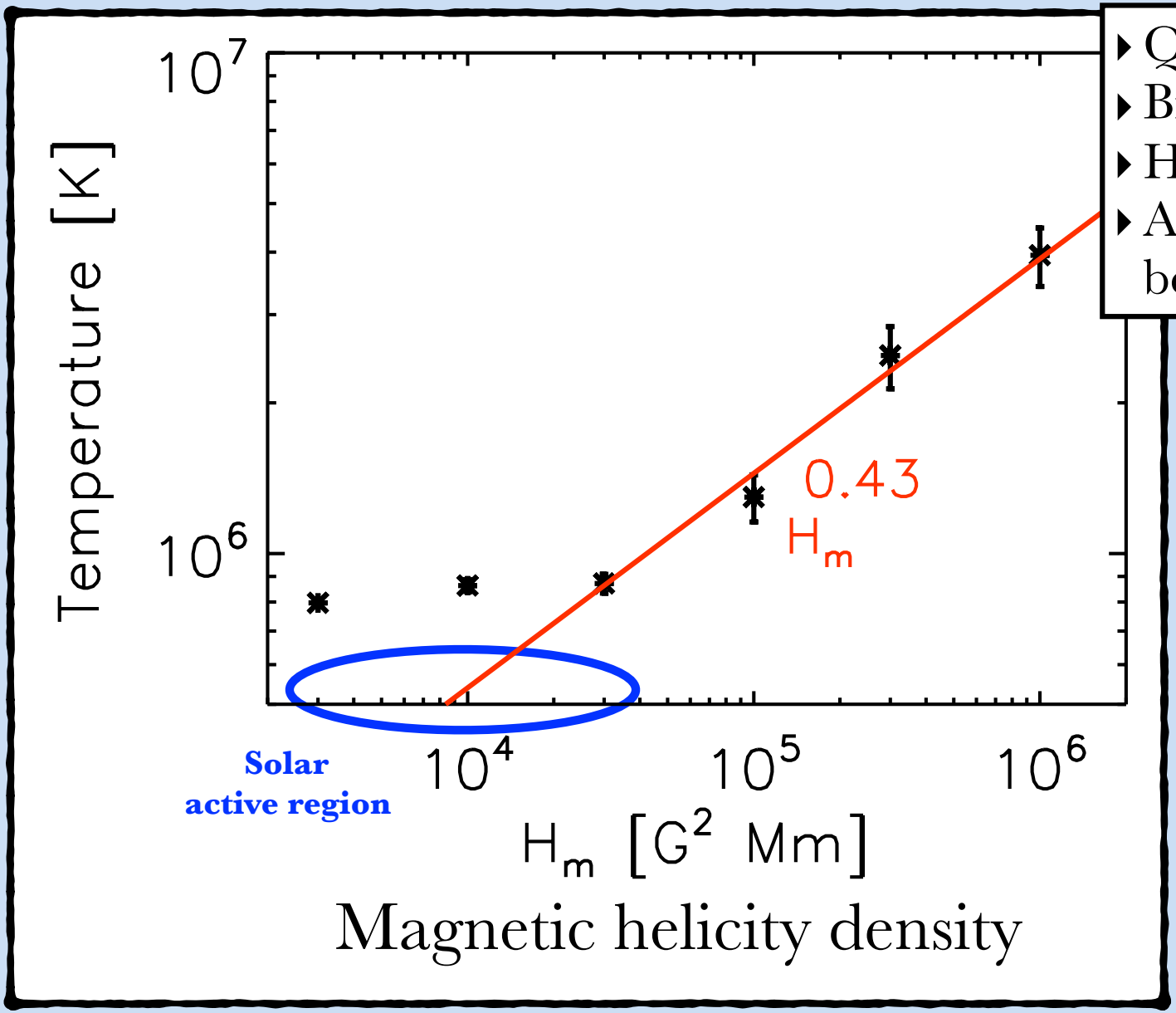


Current helicity



Current helicity is important for heating the loop

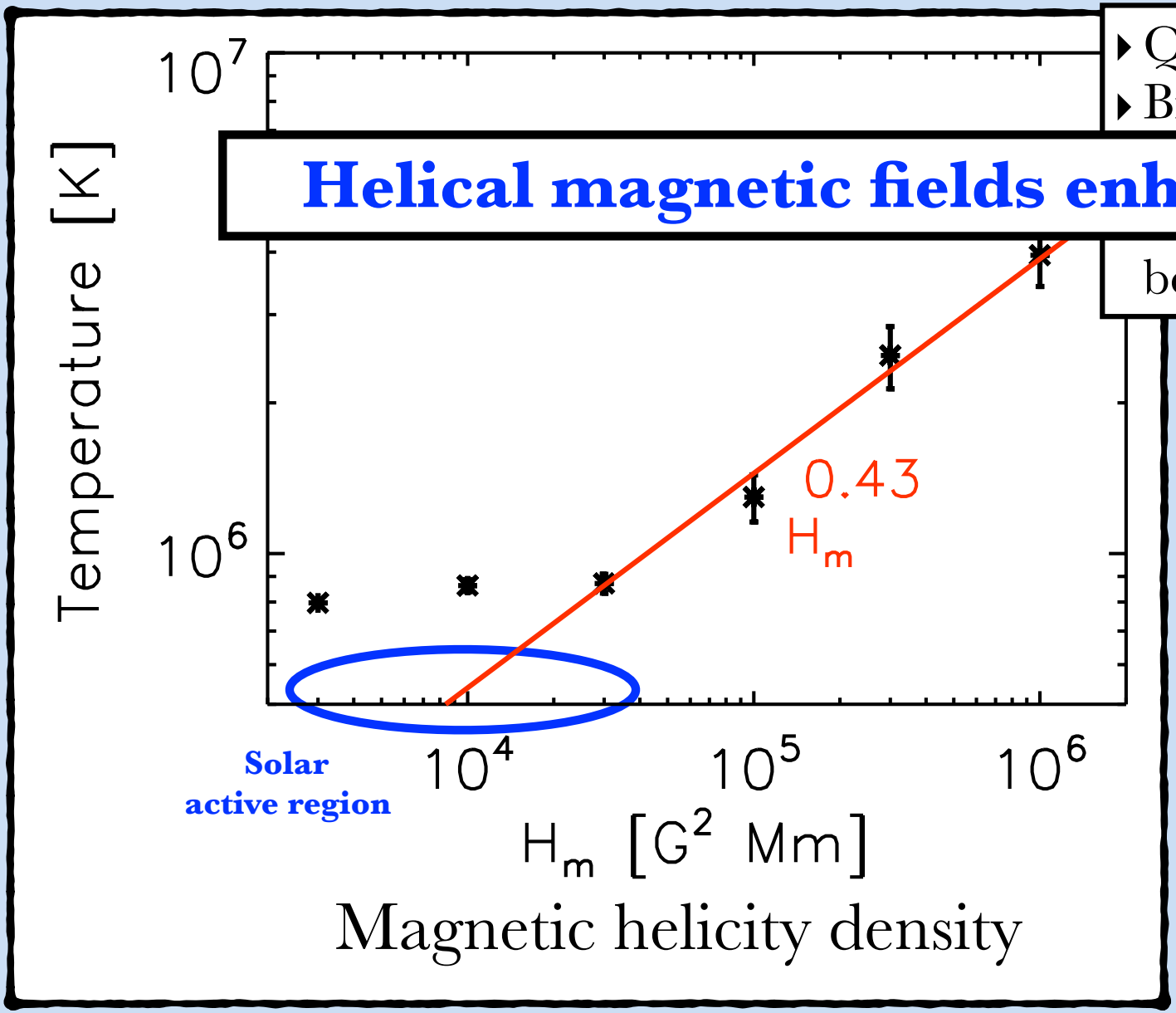
Magnetic helicity enhances heating



- Quasi-stationary loops
- Bingert & Peter 2011
- HMI vertical mag. field
- Add magnetic helicity at bottom boundary

Wright & Drake 2016

Magnetic helicity enhances heating



- Quasi-stationary loops
- Bingert & Peter 2011

Helical magnetic fields enhance heating

bottom boundary

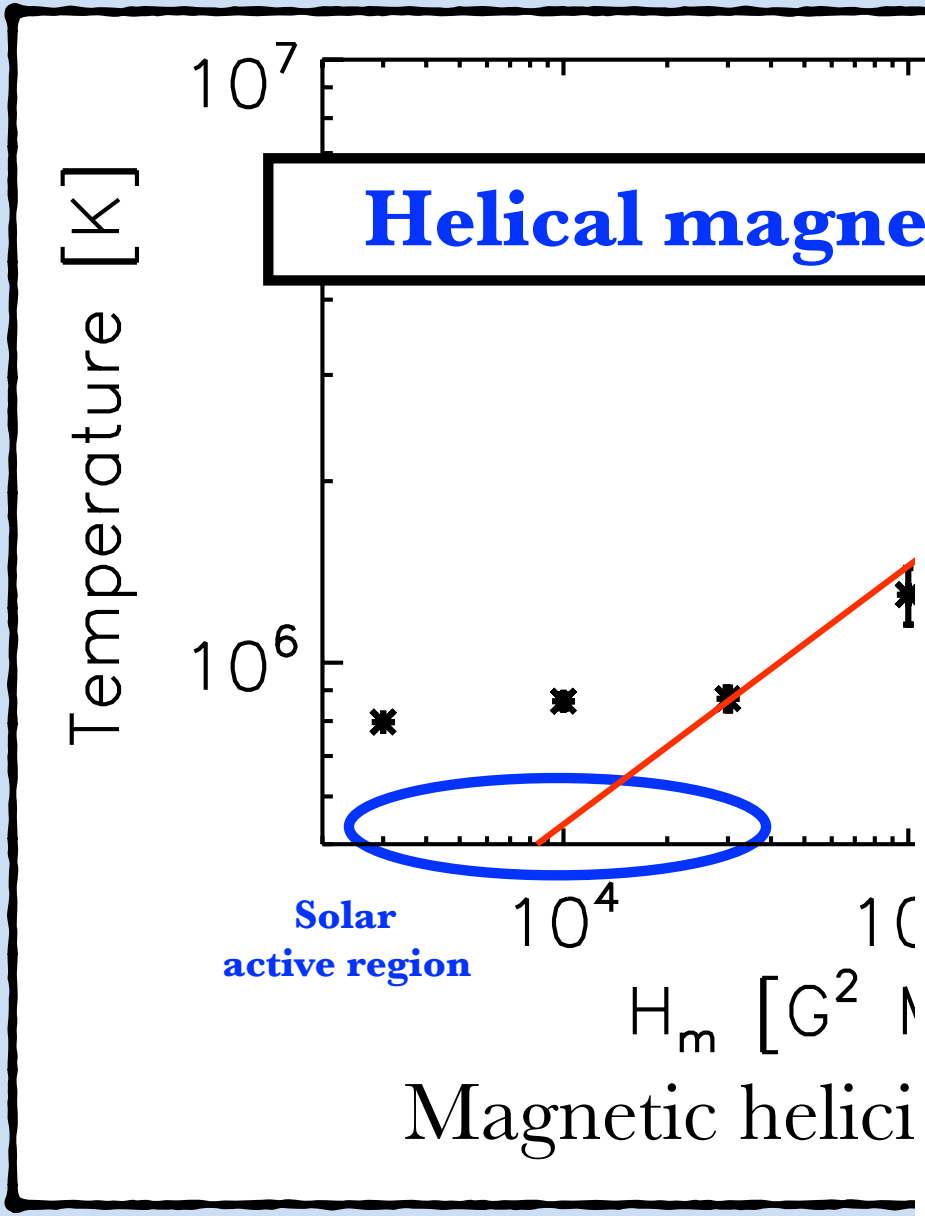
Wright & Drake 2016

Magnetic helicity enhances heating

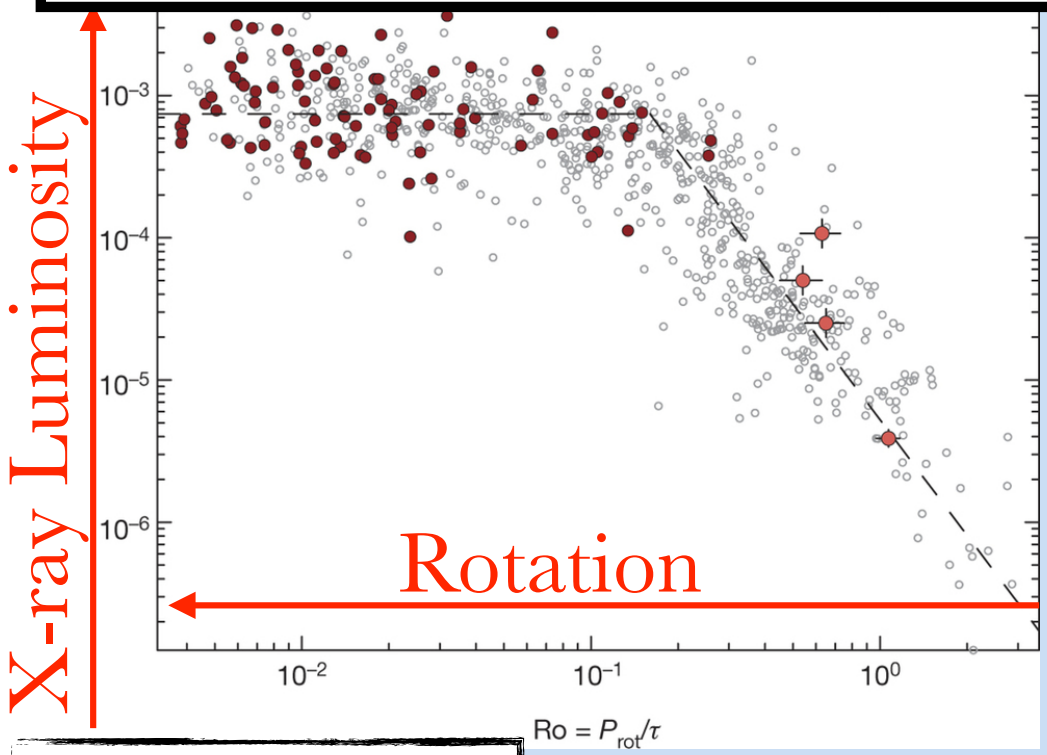
- Quasi-stationary loops
- Bingert & Peter 2011

Helical magnetic fields enhance heating

bottom boundary



Rotation-Activity Relation



Wright & Drake 2016

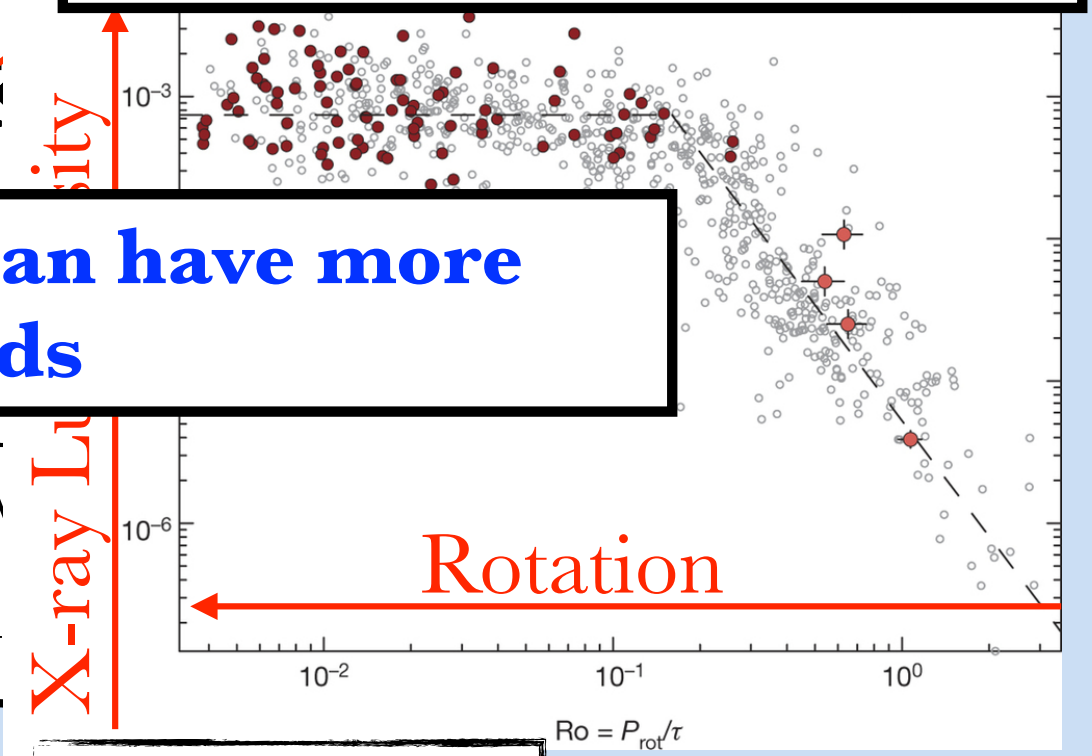
Magnetic helicity enhances heating

- Quasi-stationary loops
- Bingert & Peter 2011

Helical magnetic fields enhance heating

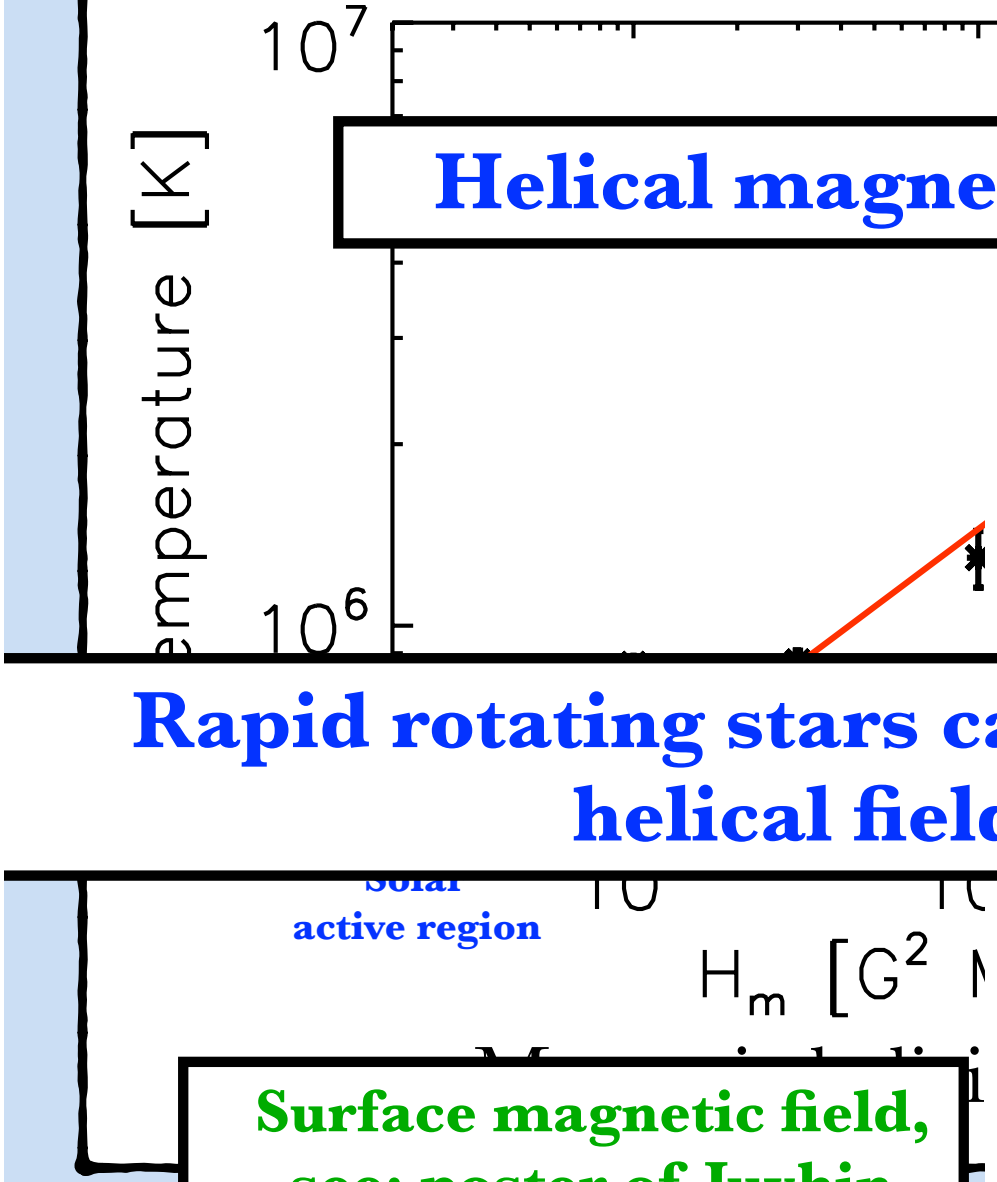
bottom boundary

Rotation-Activity Relation



Wright & Drake 2016

Rapid rotating stars can have more helical fields



Surface magnetic field, see: poster of Juxhin P-04

Conclusions

Loop above emerging active region shows helical current structure

Bipolar current structure at each footpoint; movement of footpoints

Plasma flows into the loop drive non-potential magnetic field

Loop cannot be described by force-free modelling

Heating and emission correlate with current helicity

Magnetic helicity injection leads to higher temperatures

Helical magnetic field can play an important role in understanding the Rotation-Activity-Relation of stars