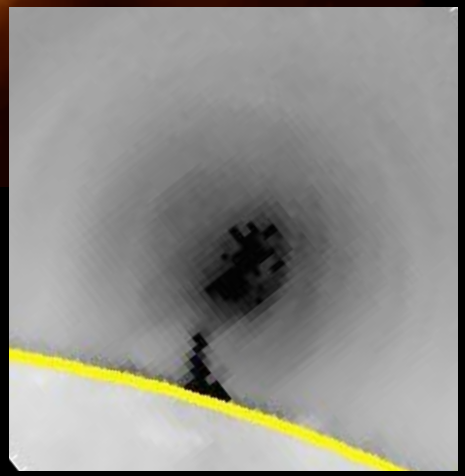
Prominence Cavities

Sarah Gibson

Prominence Cavities

Sarah Gibson

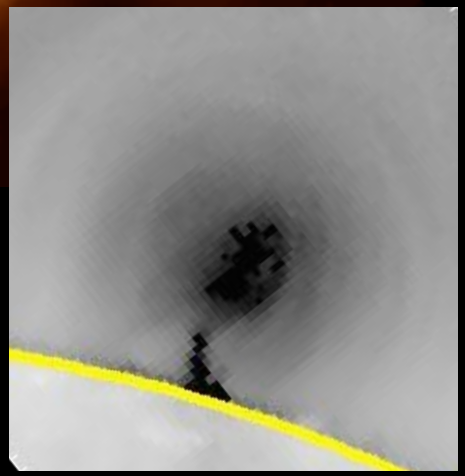
Lollypops,



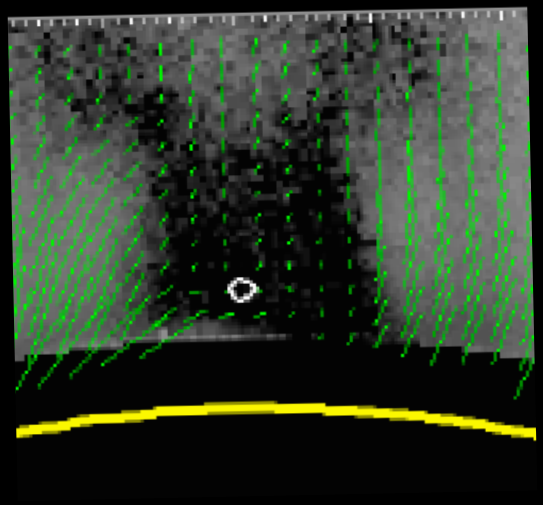
Prominence Cavities

Sarah Gibson

Lollypops,



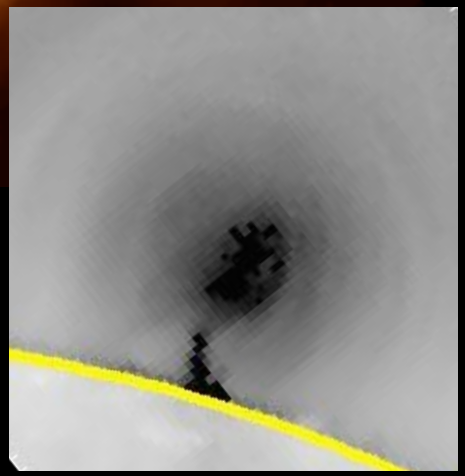
lagomorphs,



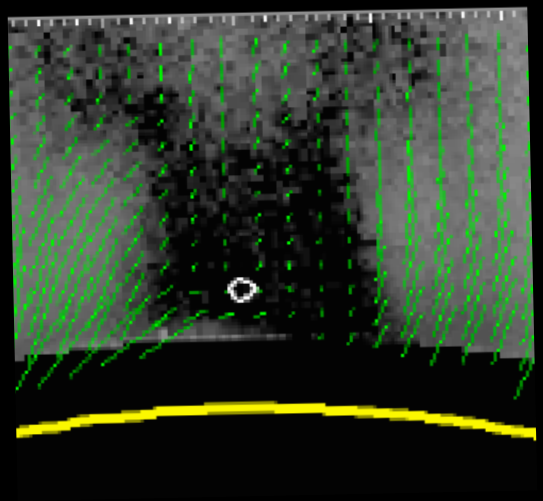
Prominence Cavities

Sarah Gibson

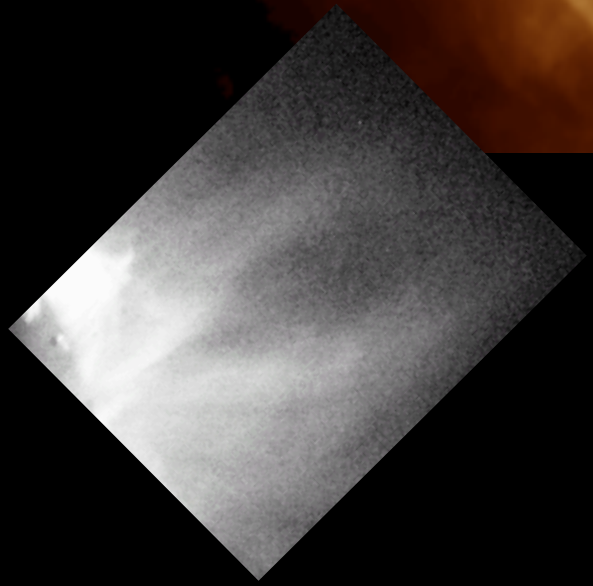
Lollypops,



lagomorphs,



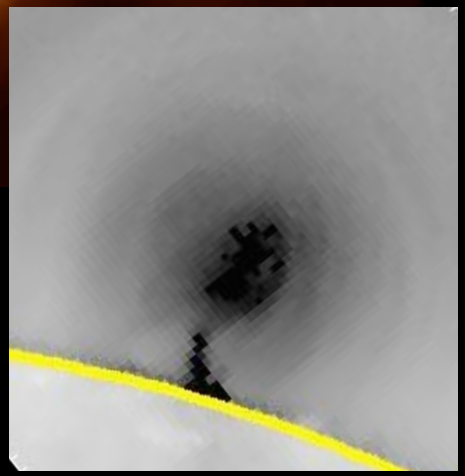
and lift-off!



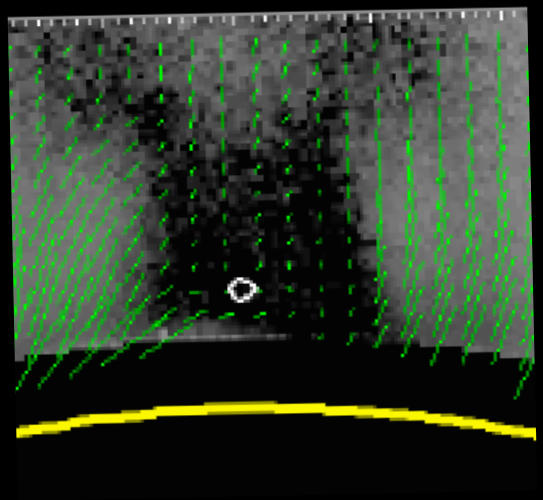
Prominence Cavities

Sarah Gibson

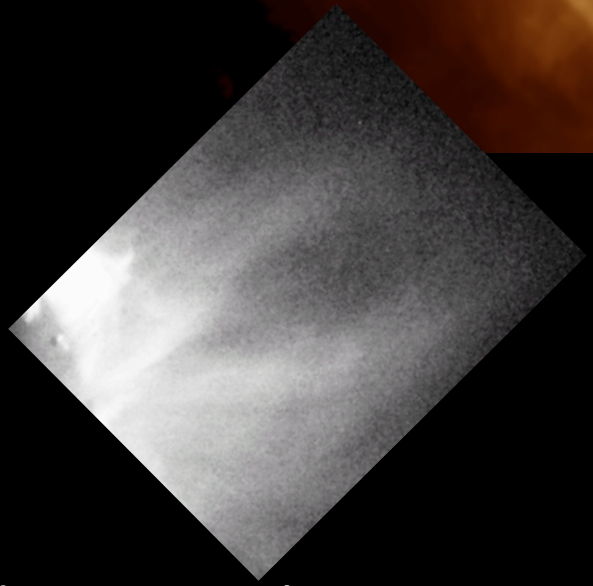
Lollypops,



lagomorphs,



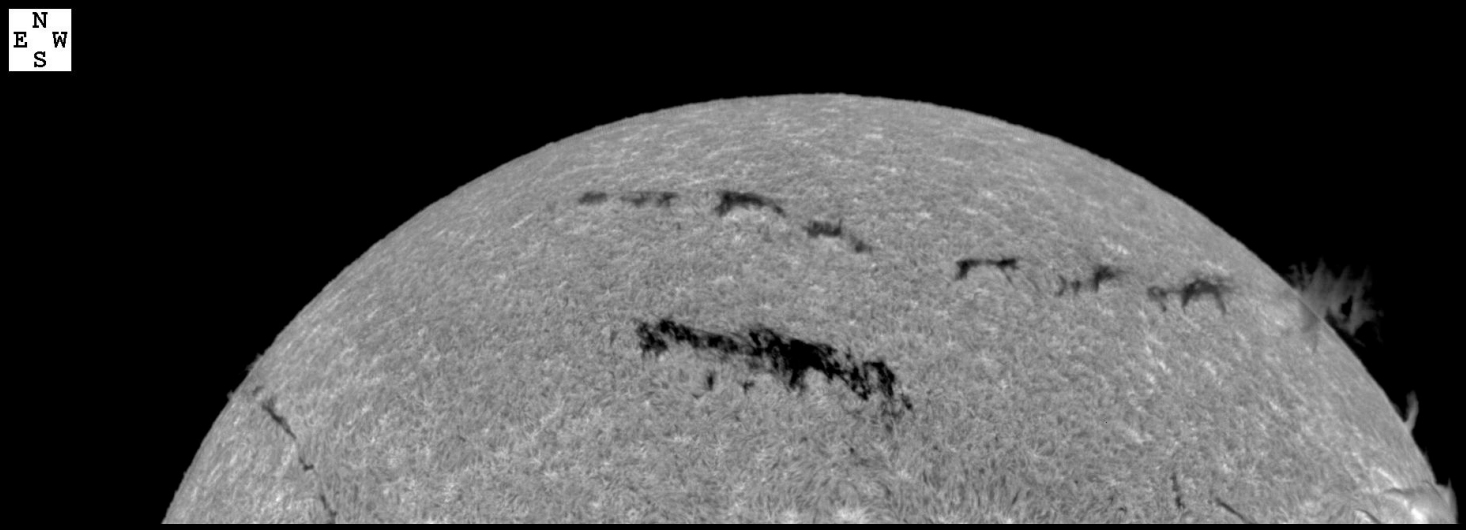
and lift-off!

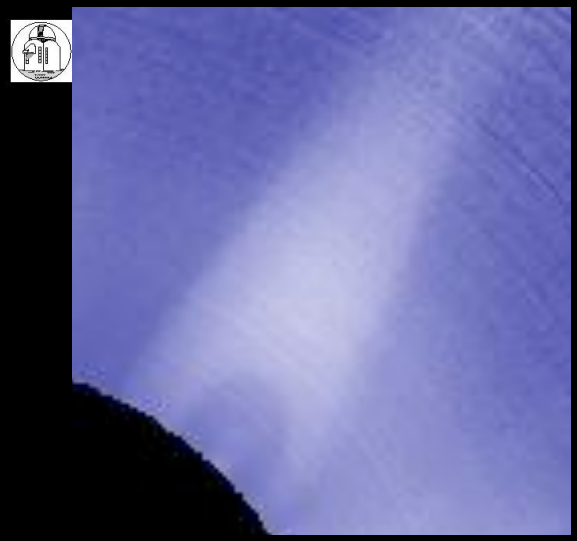


Thanks to Urszula Bak-Steslicka, Giuliana de Toma, Yuhong Fan, Blake Forland, Nishu Karna, Terry Kucera, Laurel Rachmeler, Kathy Reeves, Durgesh Tripathi, and Don Schmit

Prominence Cavities

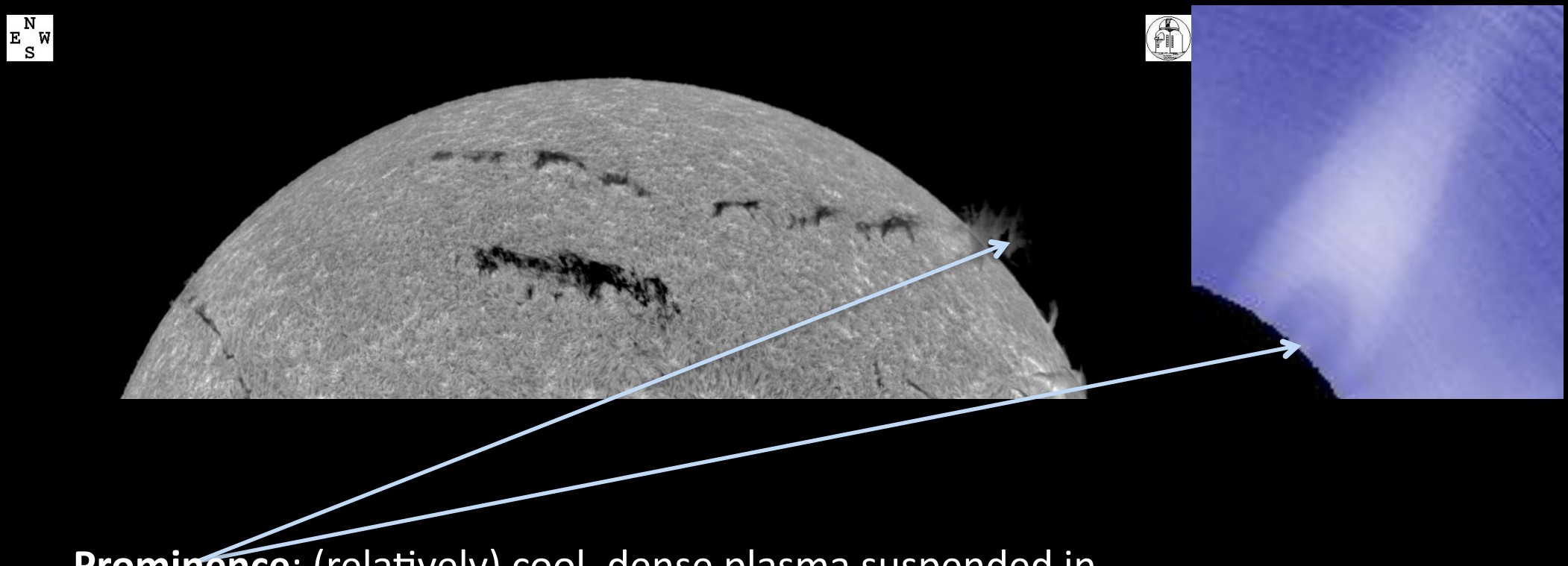
Prominences and cavities lie above solar-surface magnetic neutral lines; stable for days/weeks





Prominence Cavities

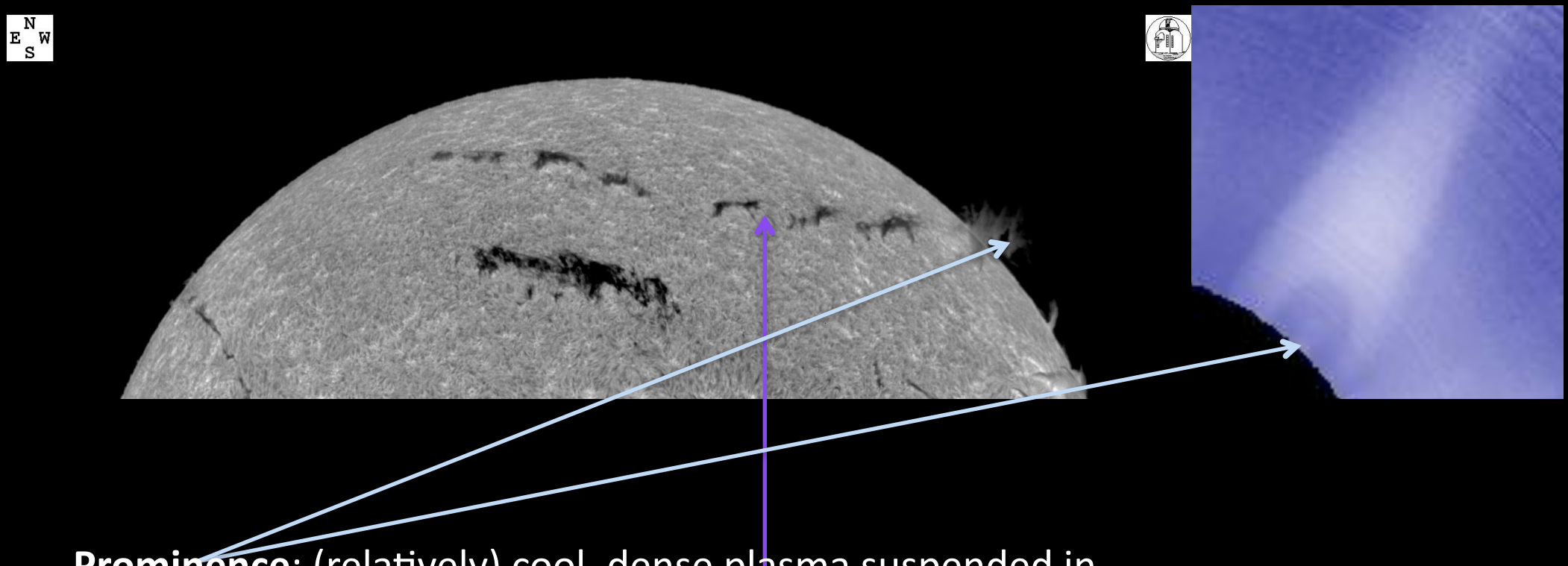
Prominences and cavities lie above solar-surface magnetic neutral lines; stable for days/weeks



Prominence: (relatively) cool, dense plasma suspended in the corona, supported by magnetic fields

Prominence Cavities

Prominences and cavities lie above solar-surface magnetic neutral lines; stable for days/weeks

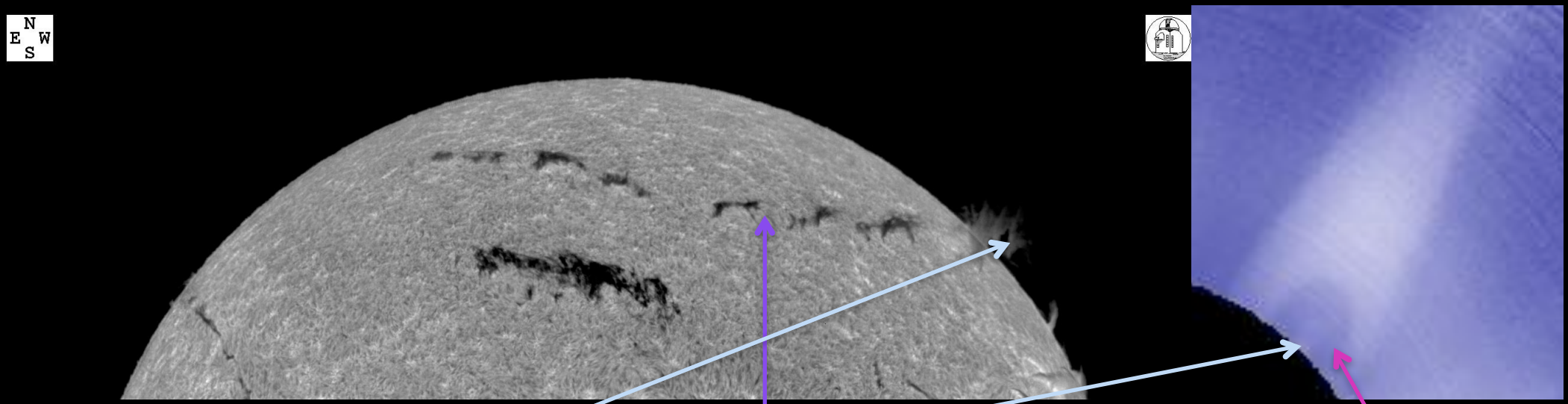


Prominence: (relatively) cool, dense plasma suspended in the corona, supported by magnetic fields

Called a **filament** if seen on the solar disk

Prominence Cavities

Prominences and cavities lie above solar-surface magnetic neutral lines; stable for days/weeks

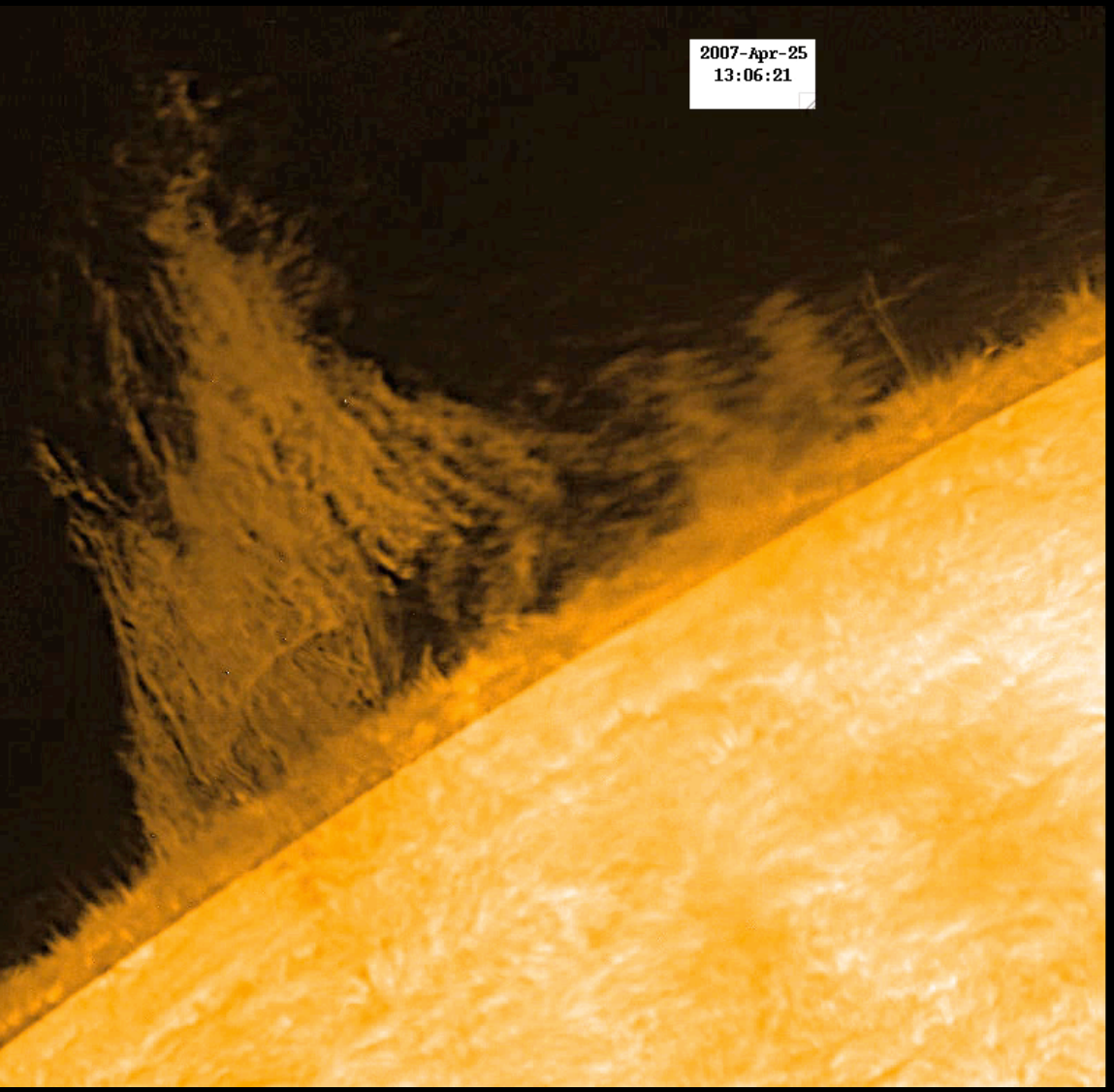


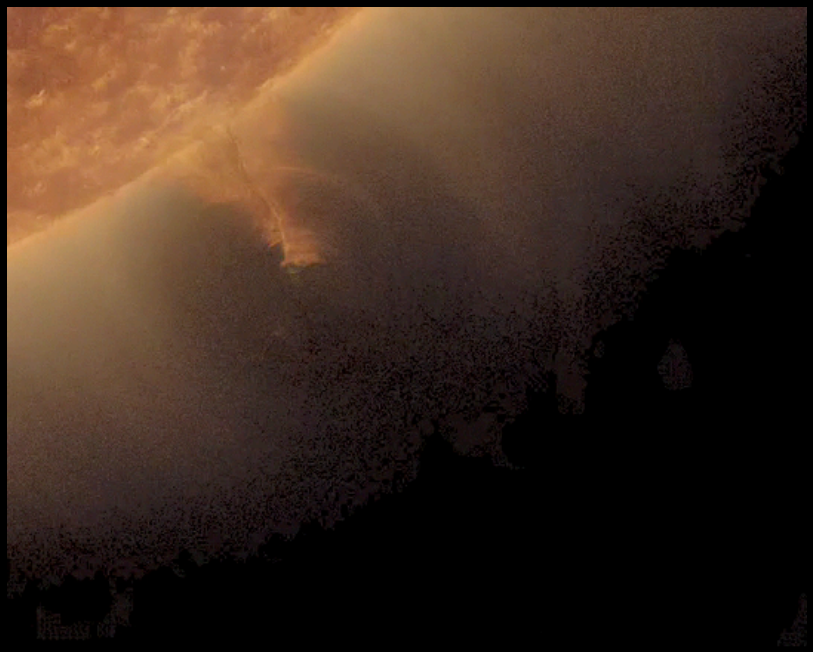
Prominence: (relatively) cool, dense plasma suspended in the corona, supported by magnetic fields

Called a **filament** if seen on the solar disk

Surrounded by dark, **coronal cavity**

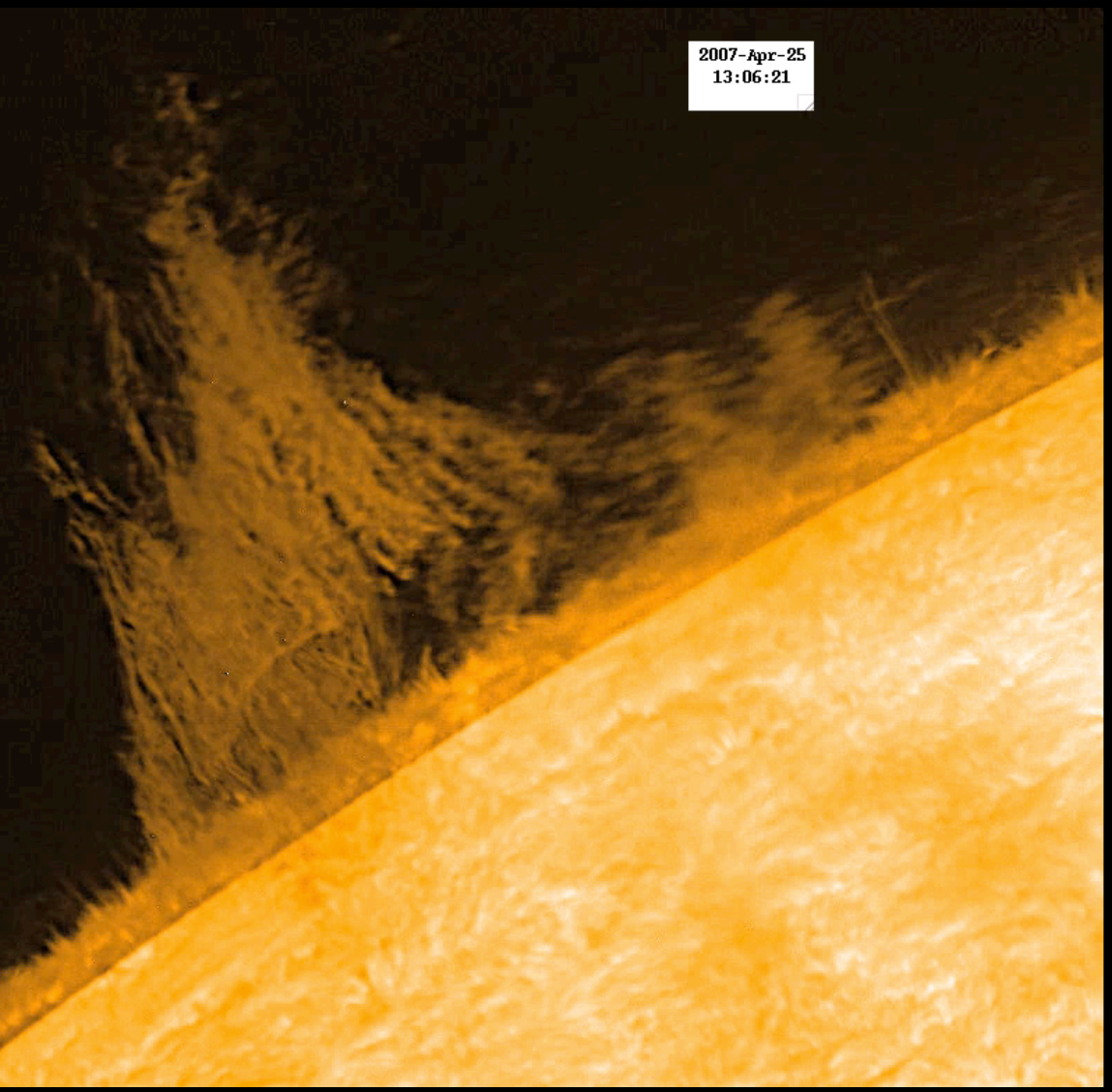
Prominence Cavities





Li et al. 2012

Prominence Cavities



…Actually they are quite dynamic when you look close enough -- but on large-scale, they pretty much stay put….

Li et al. 2012

Prominence Cavities

…until they don't.

Coronal Mass Ejection

Prominence Cavities

…until they don't.

Coronal Mass Ejection

Prominence Cavities

…until they don't.

Coronal Mass Ejection

Outline

Based on recent review chapter in new book:

Solar Prominences, Astrophysics and Space Science Library, Vol. 415, Vial, Jean-Claude, Engvold, Oddbjorn (Eds.), Springer, 2015

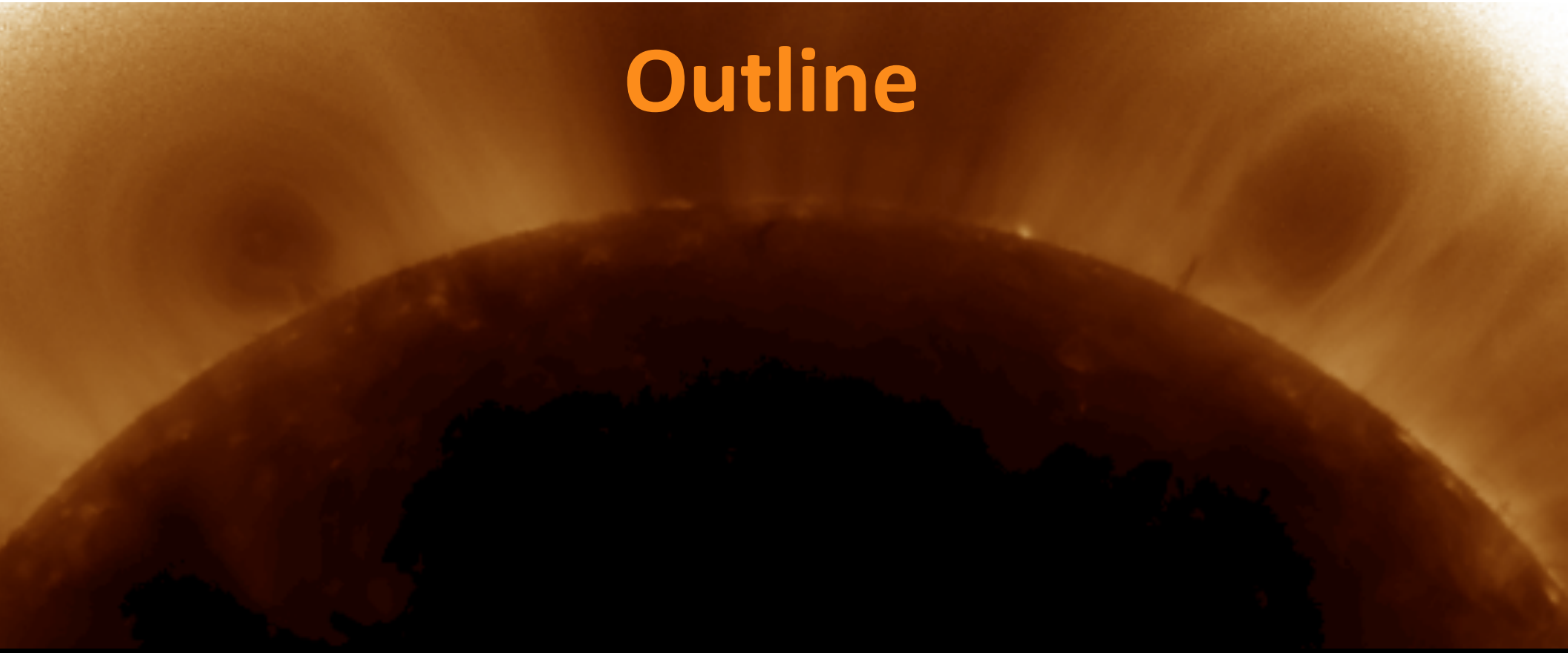
Outline

Based on recent review chapter in new book:

Solar Prominences, Astrophysics and Space Science Library, Vol. 415, Vial, Jean-Claude, Engvold, Oddbjorn (Eds.), Springer, 2015

(see also chapter by J. Karpen)

Outline



Outline

- **Ubiquitous**

Outline

- Ubiquitous
- Prolate-elliptical arched-cylindrical (croissant-like) morphology

Outline

- Ubiquitous
- Prolate-elliptical arched-cylindrical (croissant-like) morphology
- Low density relative to surrounding streamer (about a factor of two)

Outline

- Ubiquitous
- Prolate-elliptical arched-cylindrical (croissant-like) morphology
- Low density relative to surrounding streamer (about a factor of two)
- Multithermal, with flows spatially and temporally linking cavity and prominence

Outline

- Ubiquitous
- Prolate-elliptical arched-cylindrical (croissant-like) morphology
- Low density relative to surrounding streamer (about a factor of two)
- Multithermal, with flows spatially and temporally linking cavity and prominence
- Possess substructure tracing nested ellipses (lollypops!)

Outline

- Ubiquitous
- Prolate-elliptical arched-cylindrical (croissant-like) morphology
- Low density relative to surrounding streamer (about a factor of two)
- Multithermal, with flows spatially and temporally linking cavity and prominence
- Possess substructure tracing nested ellipses (lollypops!)
- "Lagomorphic" polarimetry

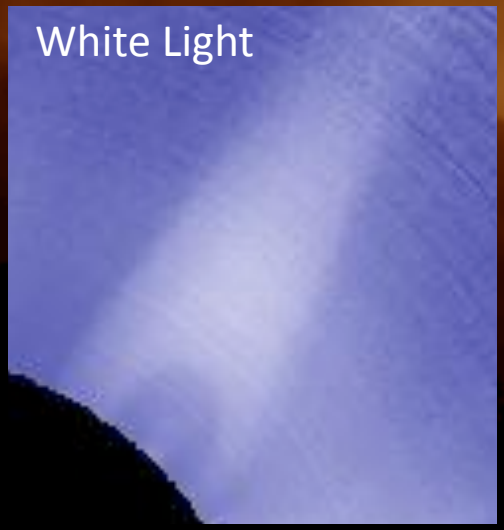
Outline

- Ubiquitous
- Prolate-elliptical arched-cylindrical (croissant-like) morphology
- Low density relative to surrounding streamer (about a factor of two)
- Multithermal, with flows spatially and temporally linking cavity and prominence
- Possess substructure tracing nested ellipses (lollypops!)
- "Lagomorphic" polarimetry
- Precursors and predictors of eruption (lift-off!)

Cavity properties: Ubiquity

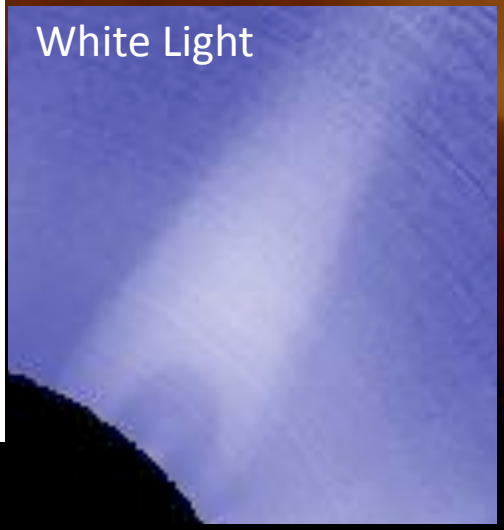
Cavity properties: Ubiquity

Cavity properties: Ubiquity



Extreme Ultraviolet

Cavity properties: Ubiquity



Extreme Ultraviolet

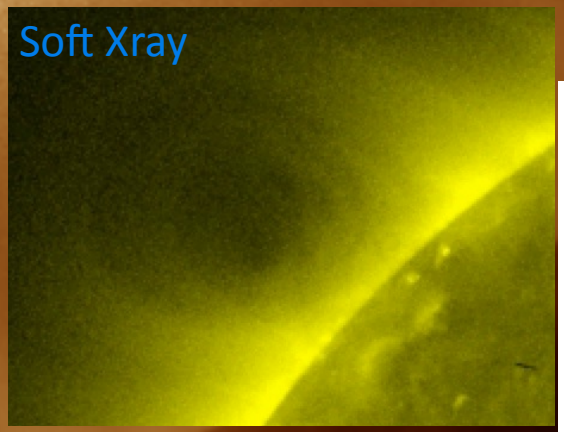
Cavity properties: Ubiquity

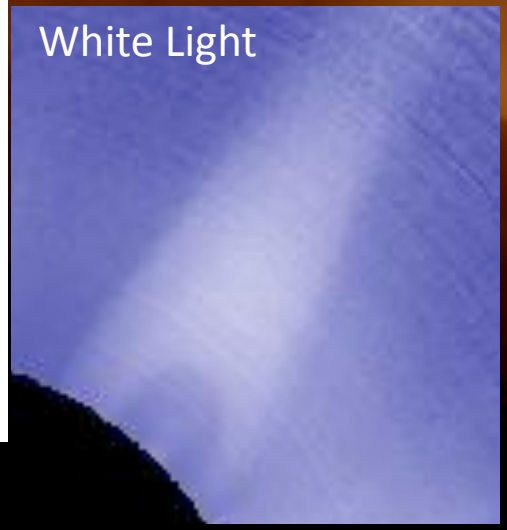
Soft Xray

White Light

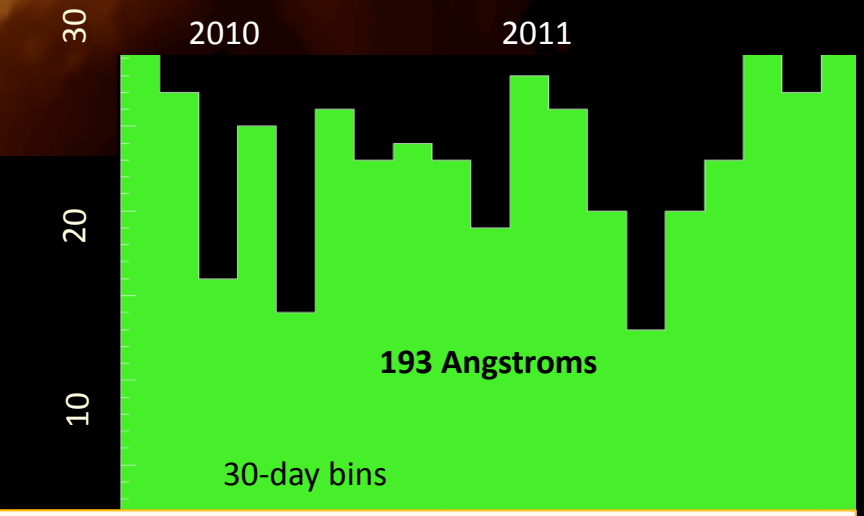
Extreme Ultraviolet

Cavity properties: Ubiquity





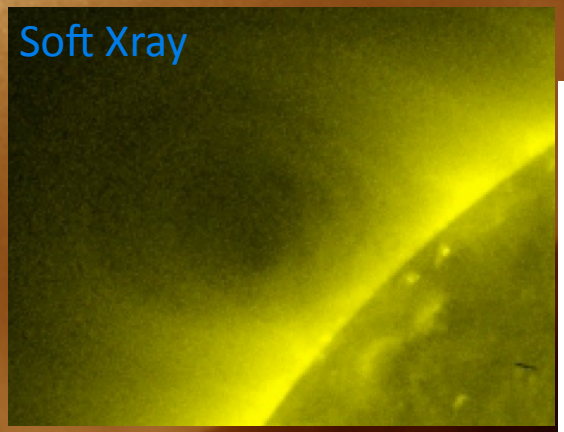
Extreme Ultraviolet

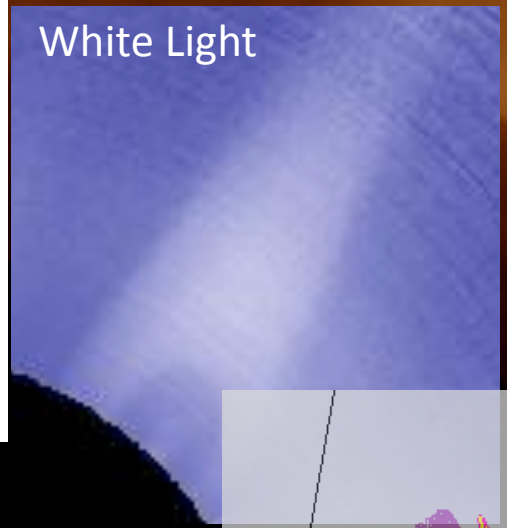


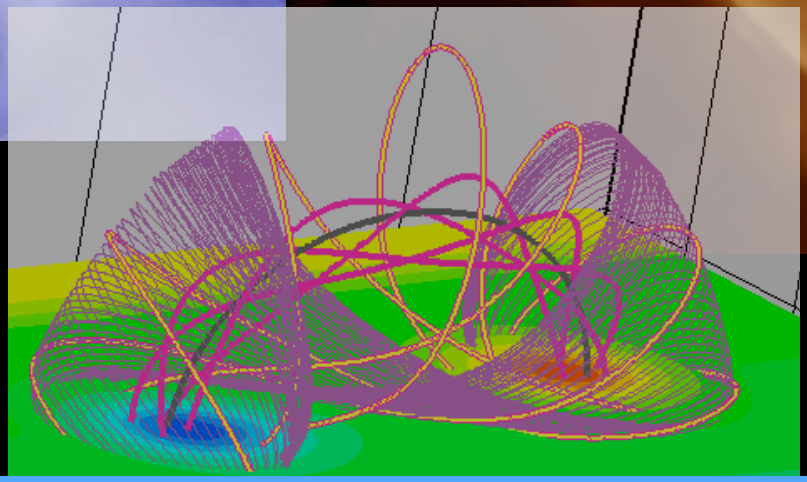
The EUV corona (193 A) during the ascending phase of the cycle has proven to be an excellent period for studying cavities: **one or more cavities are visible most days.**

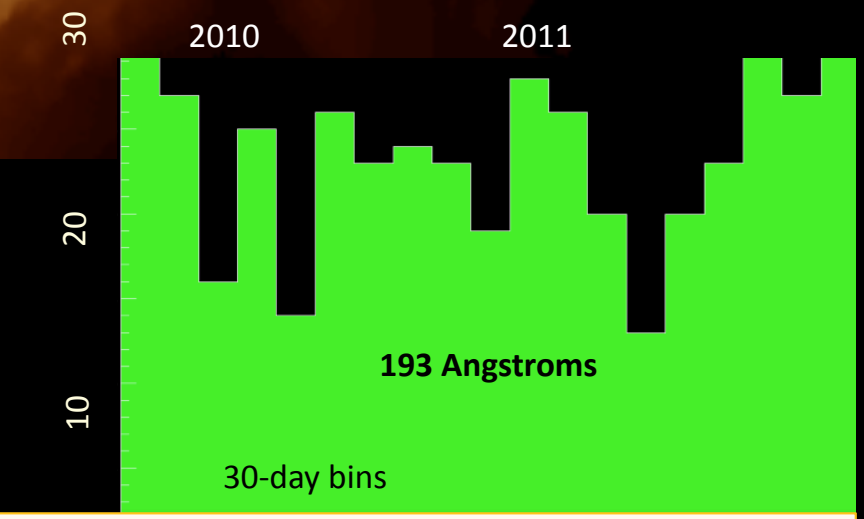
Forland et al., 2013

Cavity properties: Ubiquity









The EUV corona (193 A) during the ascending phase of the cycle has proven to be an excellent period for studying cavities: **one or more cavities are visible most days.**

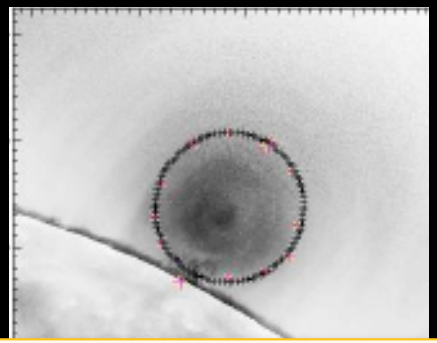
Forland et al., 2013

Interpretation: Minimum energy state that conserves helicity (flux rope). In polar crown filament (PCF), helicity can accumulate over days or weeks.

Woltjer, 1958; Taylor, 1974; Mackay, 2014)

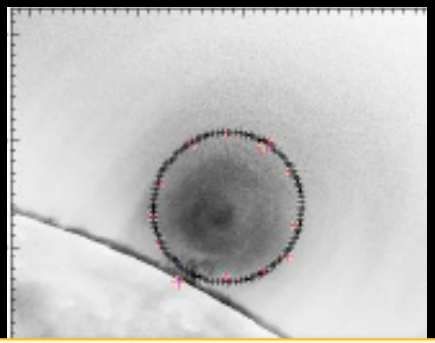
Cavity properties: Morphology

Cavity properties: Morphology

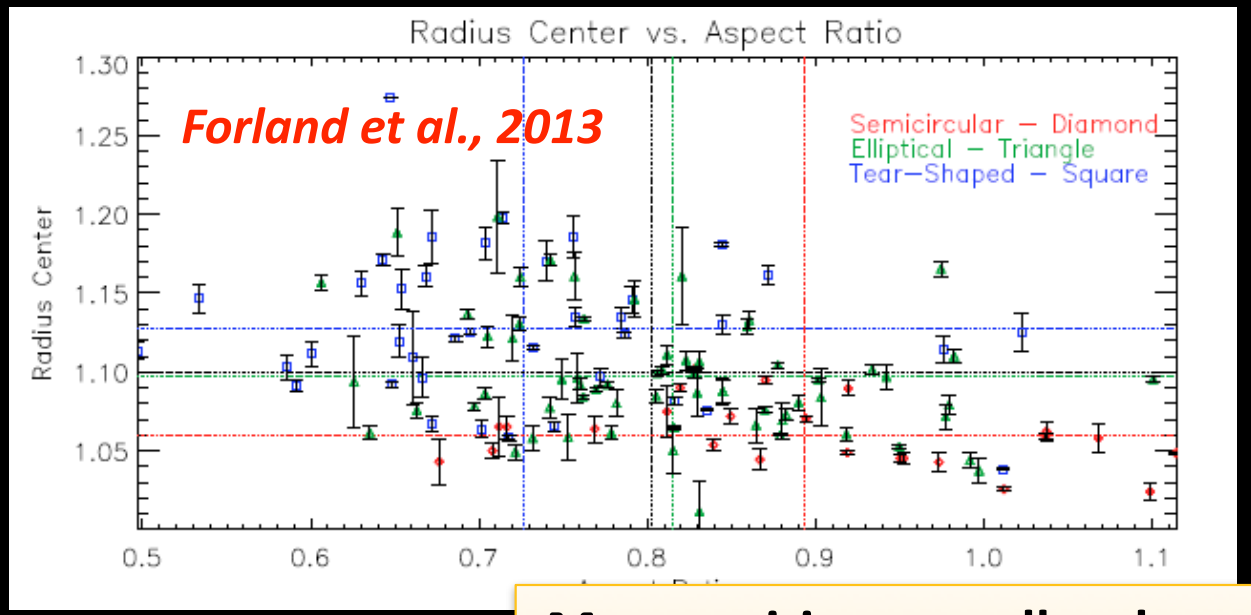


Cross-section of cavities can be fit to ellipses

Cavity properties: Morphology

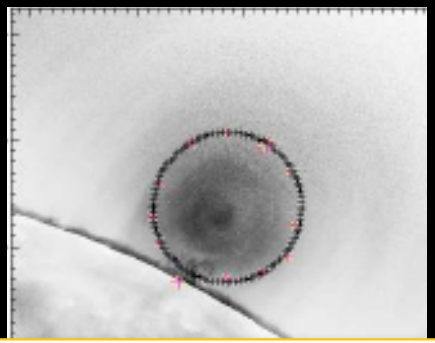


Cross-section of cavities can be fit to ellipses

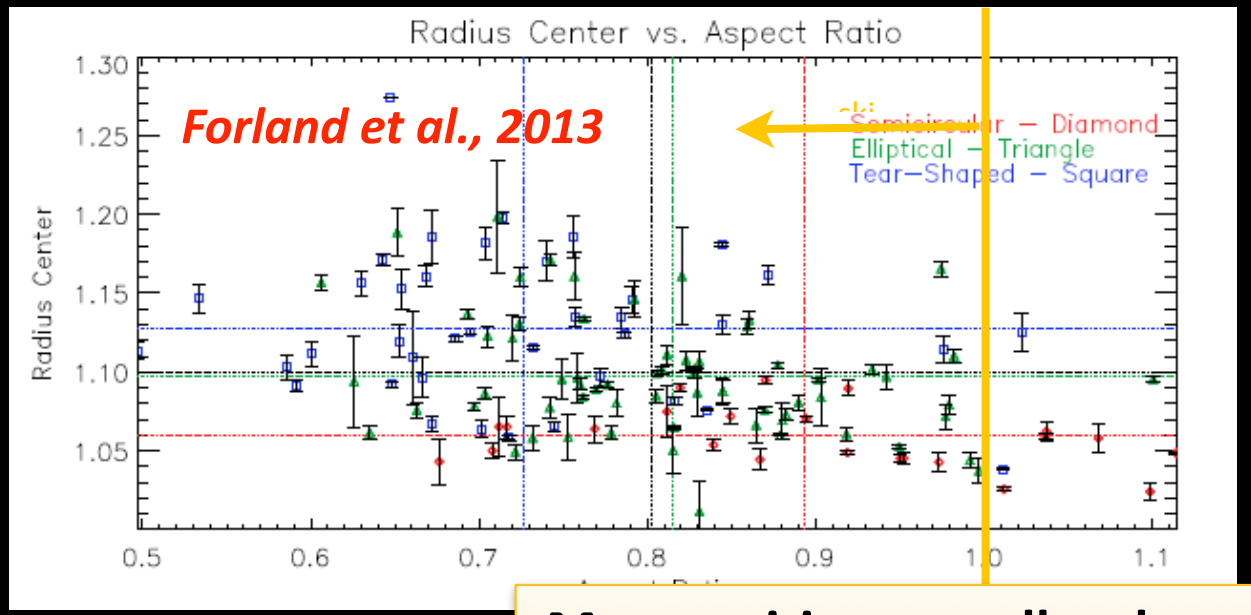


Most cavities are taller than they are wide ("skinny")

Cavity properties: Morphology

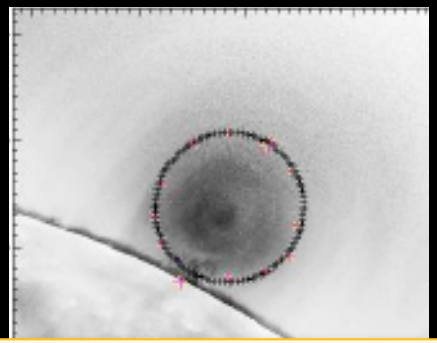


Cross-section of cavities can be fit to ellipses

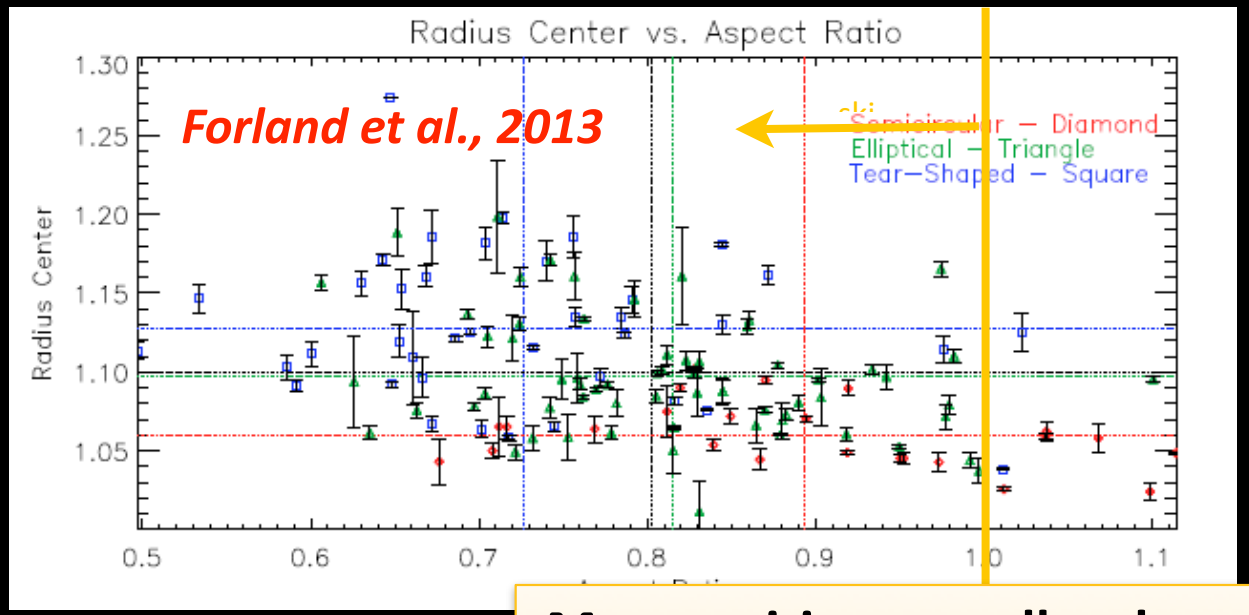


Most cavities are taller than they are wide ("skinny")

Cavity properties: Morphology

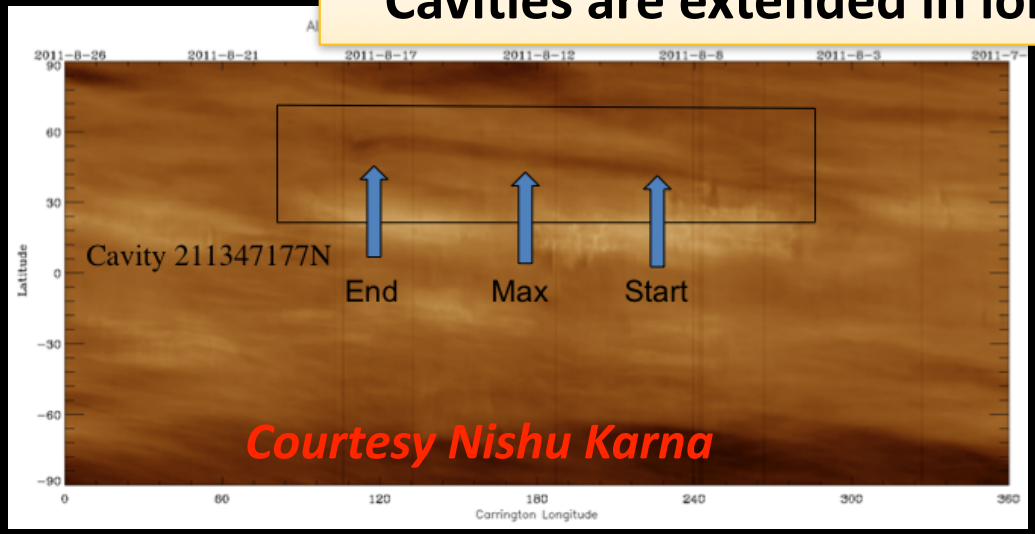


Cross-section of cavities can be fit to ellipses

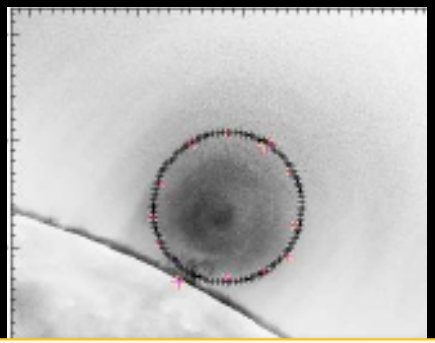


Most cavities are taller than they are wide ("skinny")

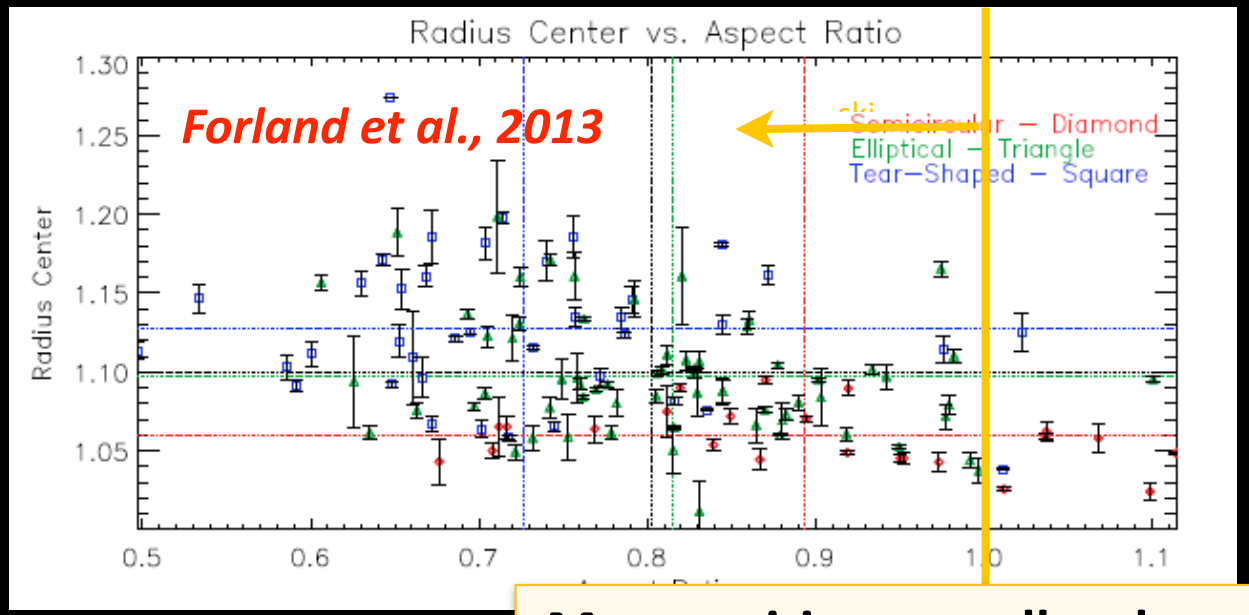
Cavities are extended in longitude



Cavity properties: Morphology

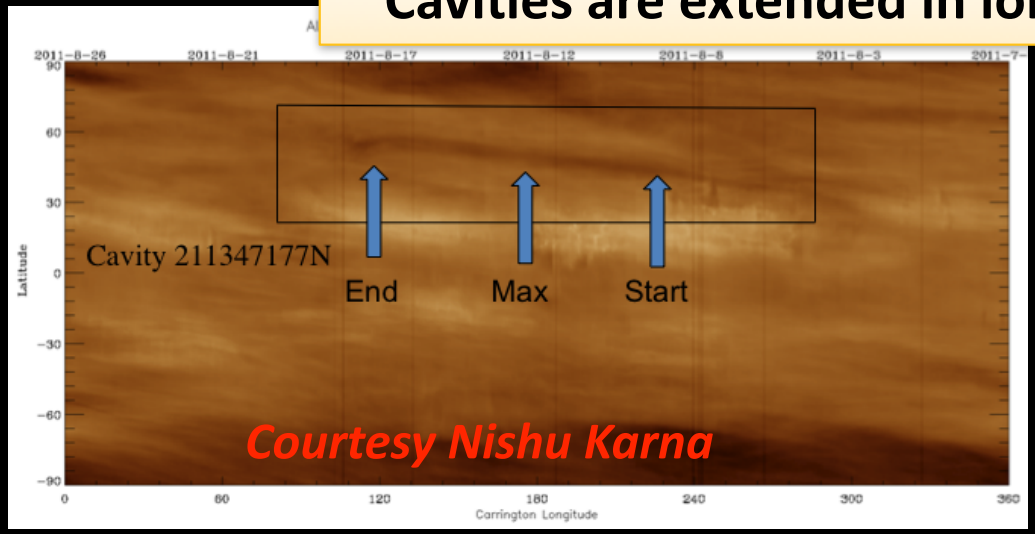


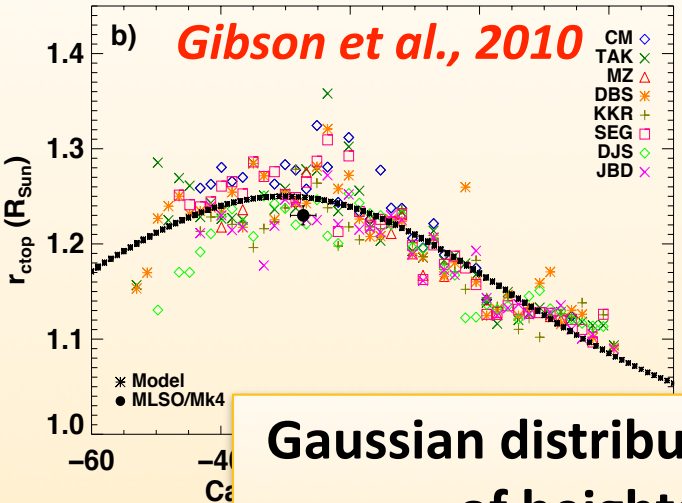
Cross-section of cavities can be fit to ellipses



Most cavities are taller than they are wide ("skinny")

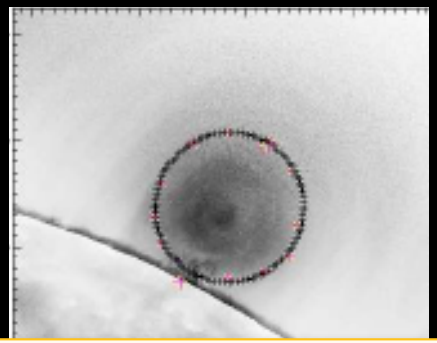
Cavities are extended in longitude



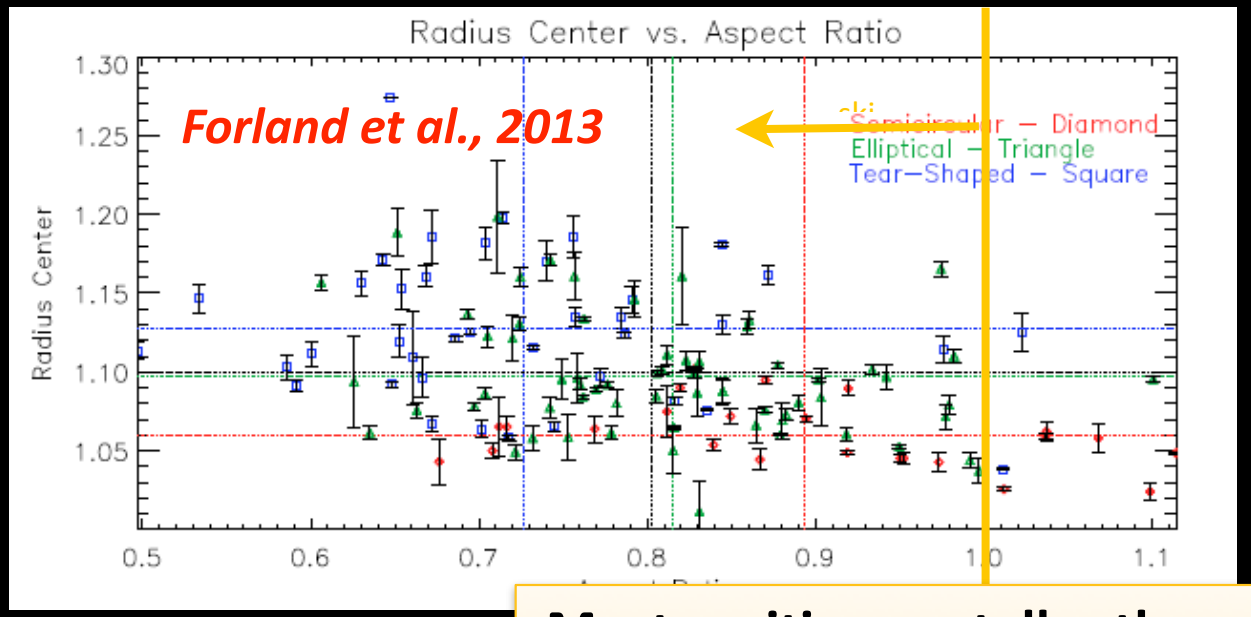


Gaussian distribution of heights

Cavity properties: Morphology

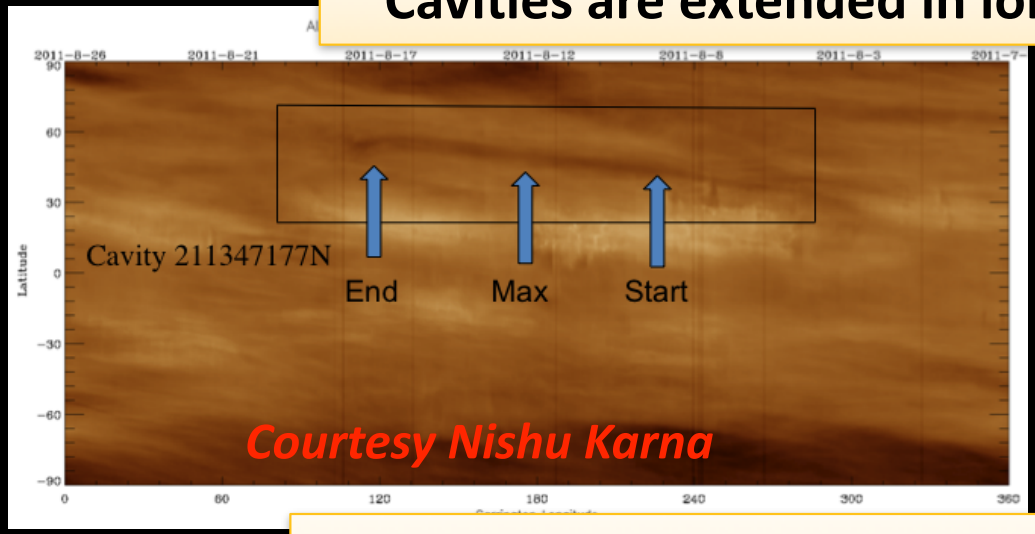


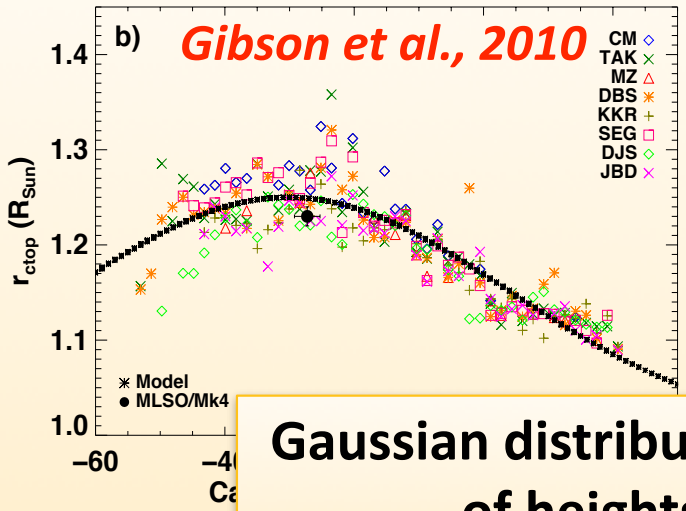
Cross-section of cavities can be fit to ellipses



Most cavities are taller than they are wide ("skinny")

Cavities are extended in longitude





Prolate-elliptical, arched-cylindrical (croissant-like) morphology

Gaussian distribution of heights

Cavity properties: Morphology

Most cavities are taller than they are wide ("skinny")

Prolate-elliptical, arched-cylindrical (croissant-like) morphology

Cavity properties: Morphology

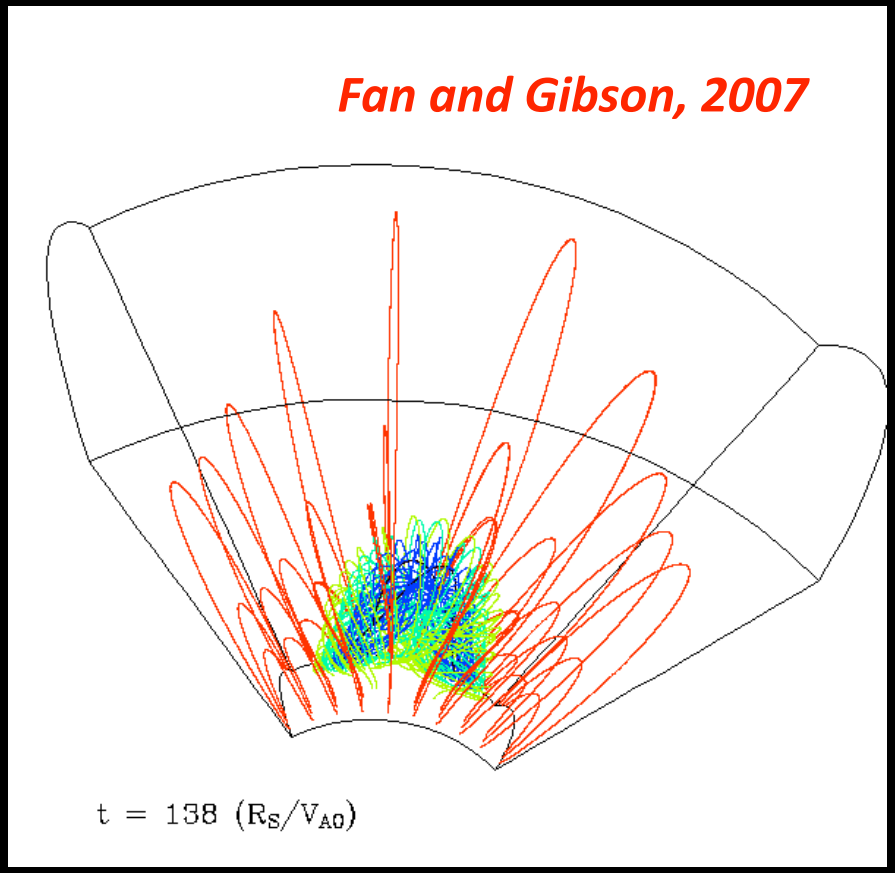
Interpretation: Expanded, but trapped, twisted flux

Most cavities are taller than they are wide ("skinny")

Prolate-elliptical, arched-cylindrical (croissant-like) morphology

Cavity properties: Morphology

Interpretation: Expanded, but trapped, twisted flux

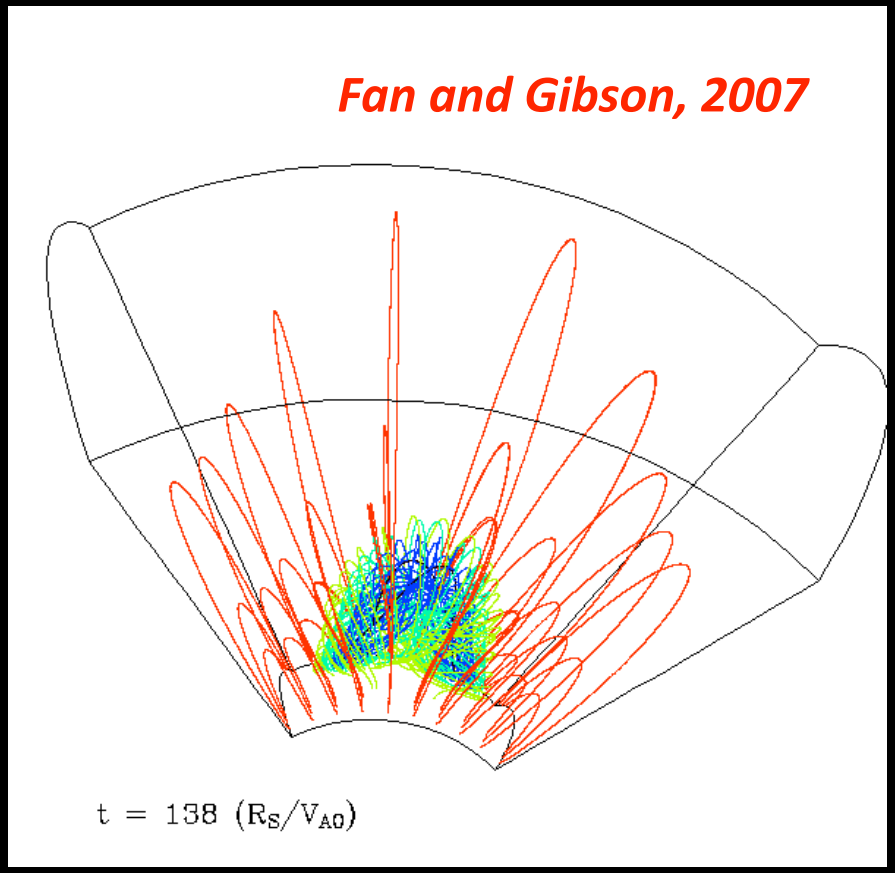


Most cavities are taller than they are wide ("skinny")

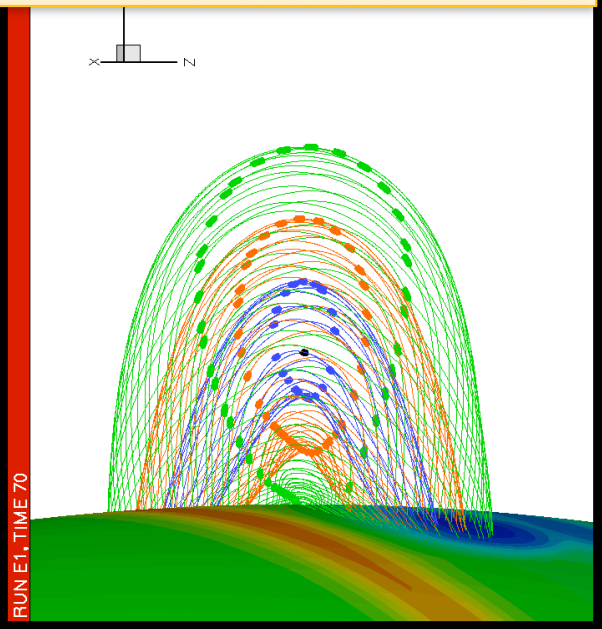
Prolate-elliptical, arched-cylindrical (croissant-like) morphology

Cavity properties: Morphology

Interpretation: Expanded, but trapped, twisted flux



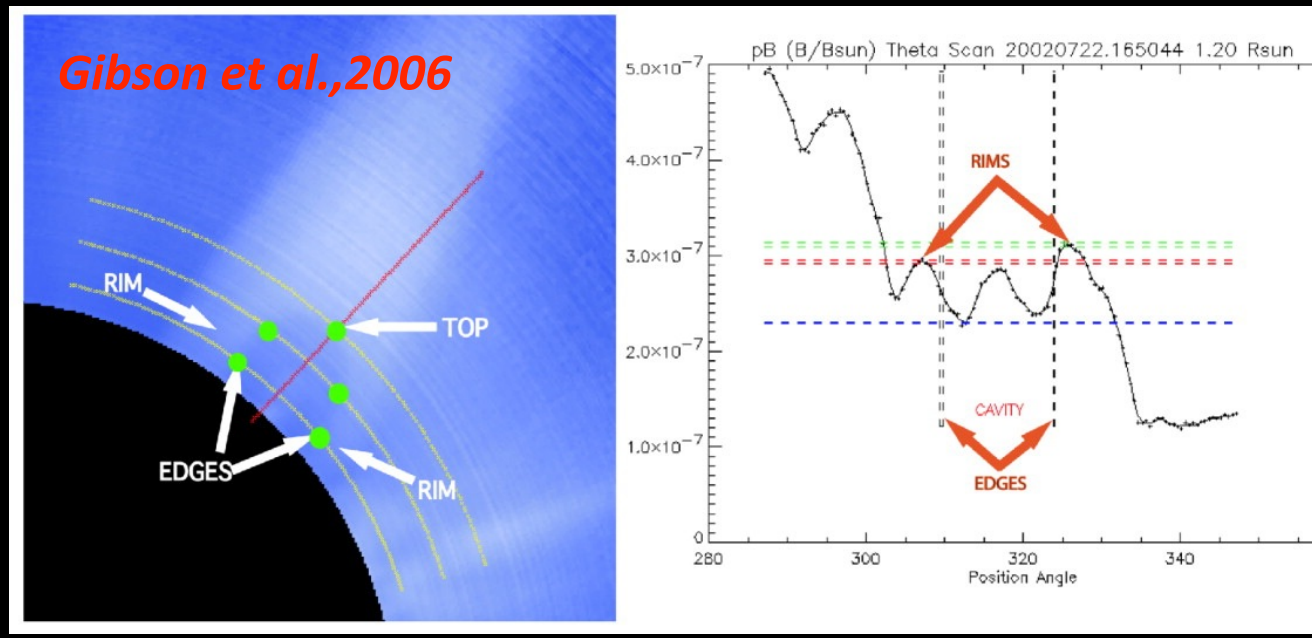
Most cavities are taller than they are wide ("skinny")



Prolate-elliptical, arched-cylindrical (croissant-like) morphology

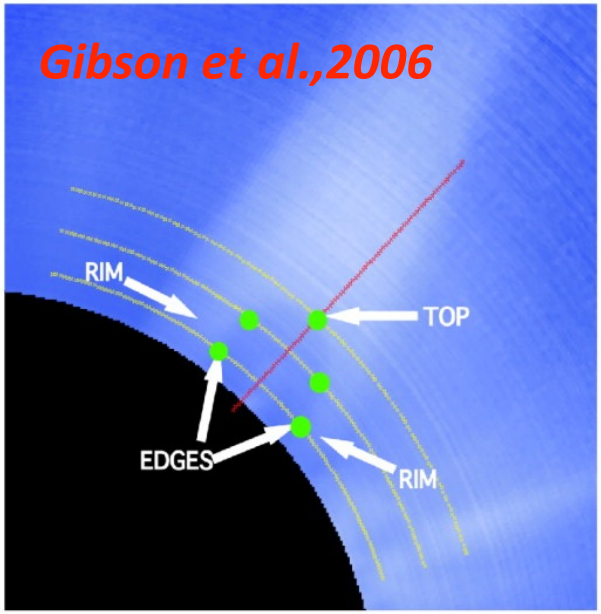
Cavity properties: Density

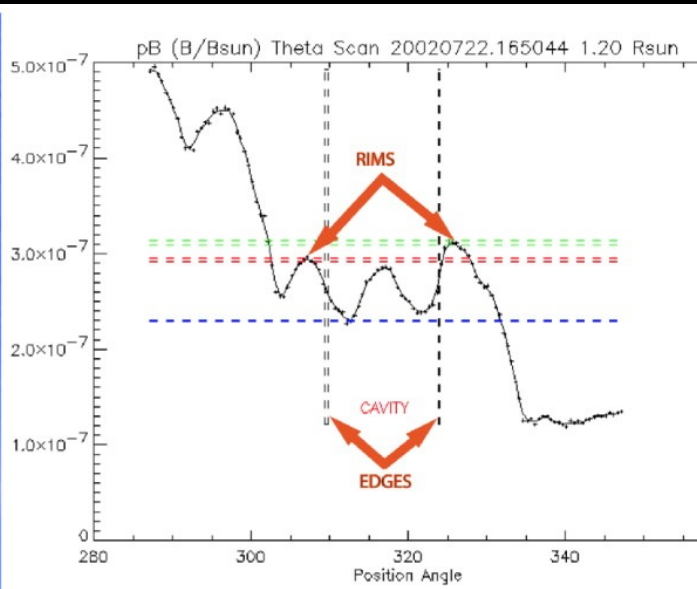
Cavity properties: Density

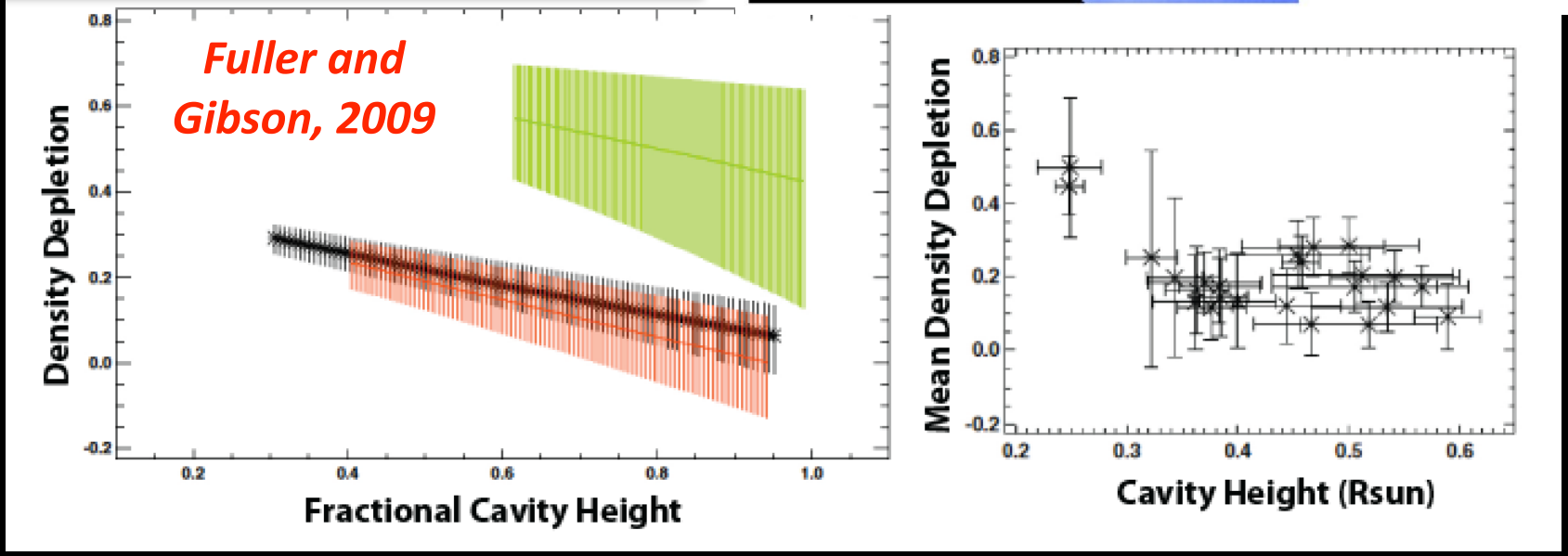


Cavity properties: Density

Analysis of 24 white-light cavities: **25% on average; 60% maximum cavity depletion (relative to surrounding streamer)**

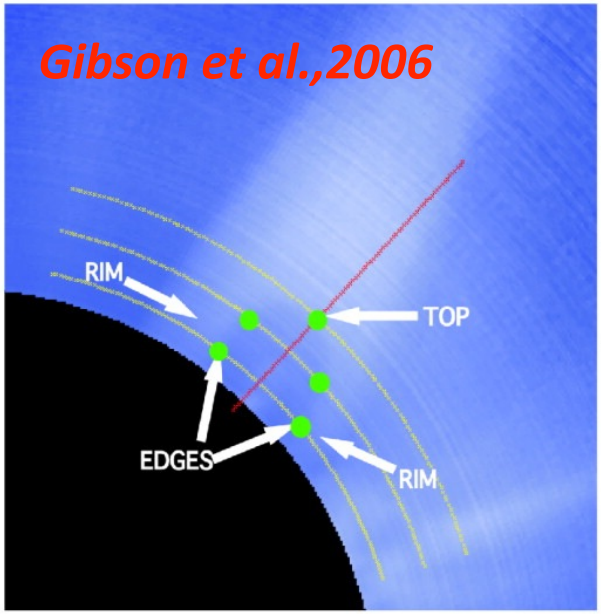


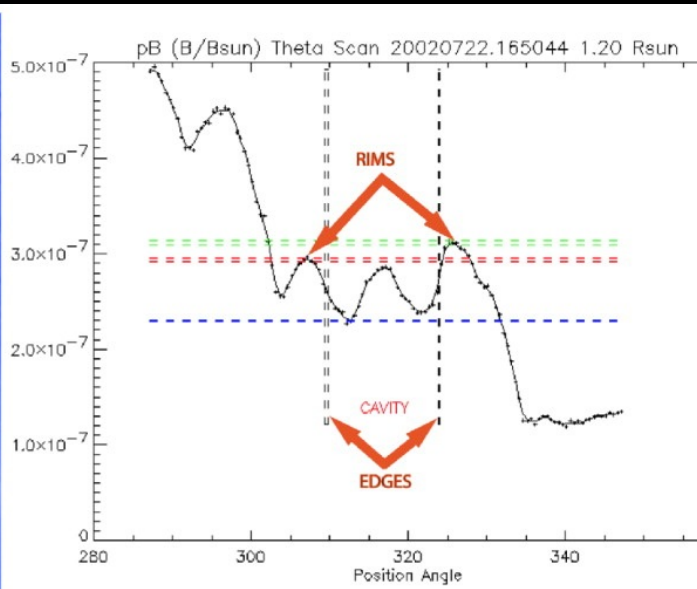


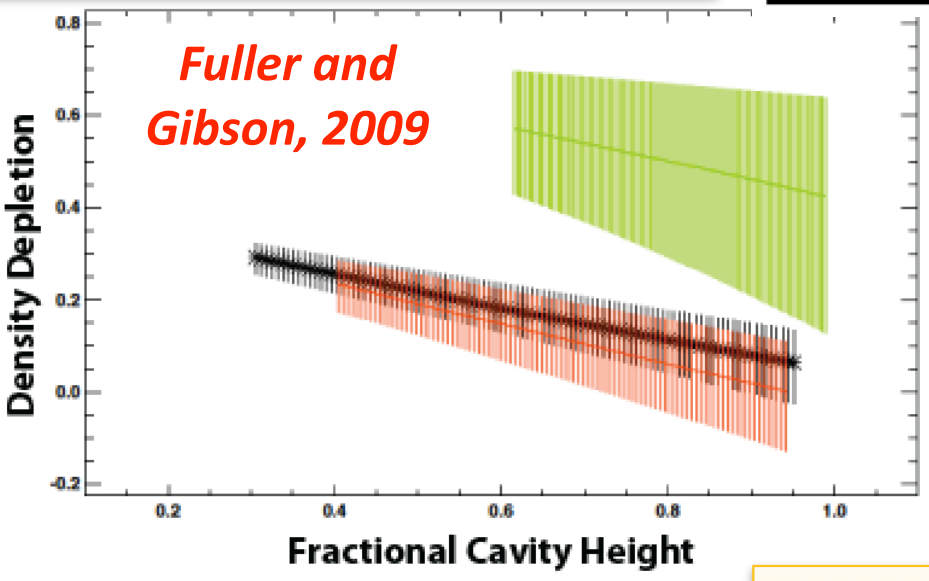


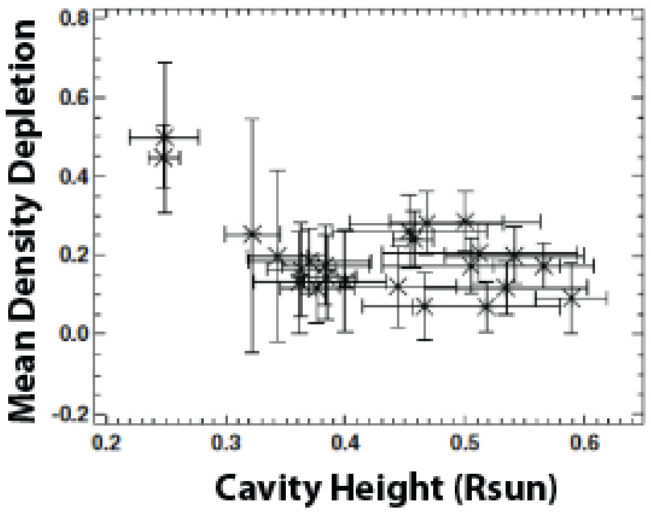
Cavity properties: Density

Analysis of 24 white-light cavities: **25% on average; 60% maximum cavity depletion (relative to surrounding streamer)**









Depletion maximum at low heights, minimum (usually zero) at top of cavity.

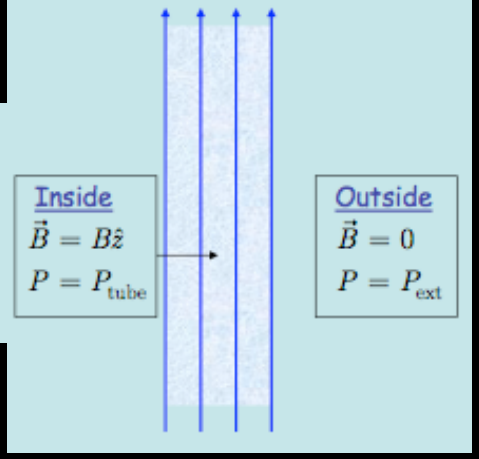
Cavity properties: Density

Cavity properties: Density

Interpretation: Flux surface/pressure jump…

$$P_{\text{tube}} + \frac{B^2}{8\pi} = P_{\text{ext}}$$

$$P_{\text{tube}} = P_{\text{ext}} - \frac{B^2}{8\pi}$$



Cavity properties: Density

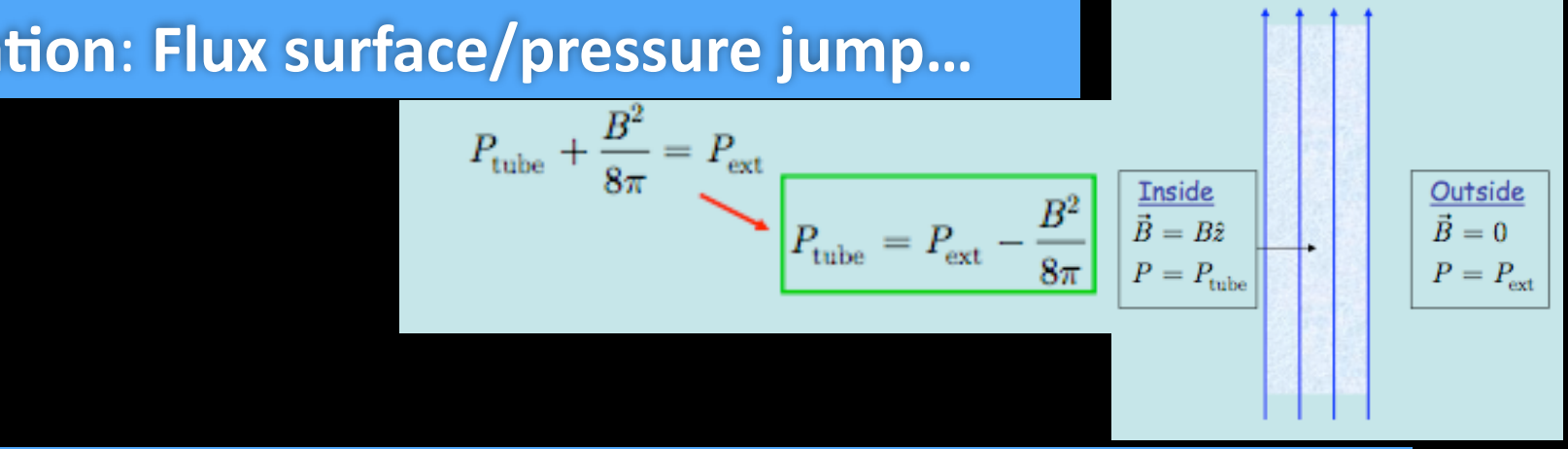
Interpretation: Flux surface/pressure jump…

$$P_{\text{tube}} + \frac{B^2}{8\pi} = P_{\text{ext}}$$

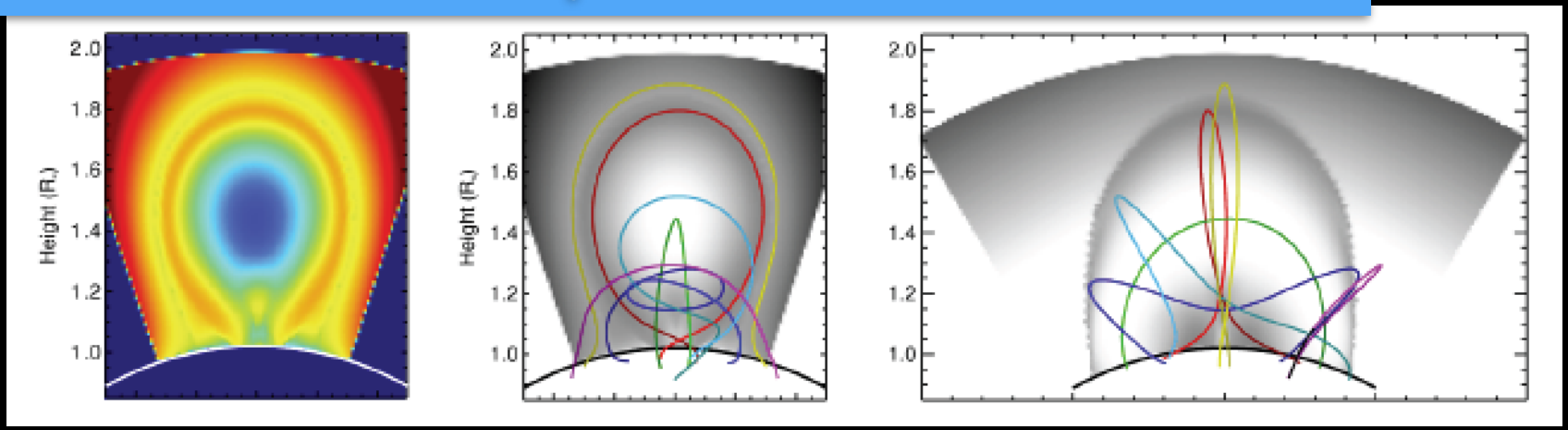
$$P_{\text{tube}} = P_{\text{ext}} - \frac{B^2}{8\pi}$$

Inside
$\vec{B} = B\hat{z}$
$P = P_{\text{tube}}$

Outside
$\vec{B} = 0$
$P = P_{\text{ext}}$



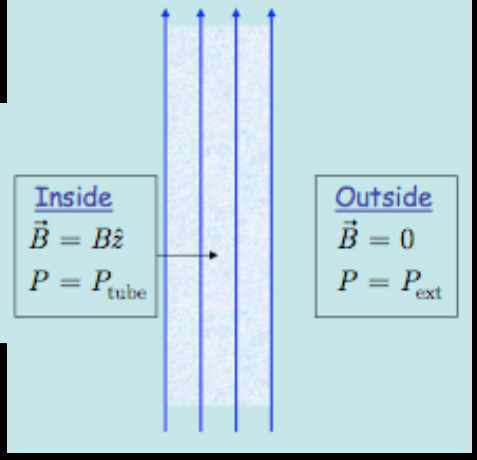
…short, axial field = density cavity. Hydrostatic model —> 35% depletion *Schmit and Gibson, 2014*



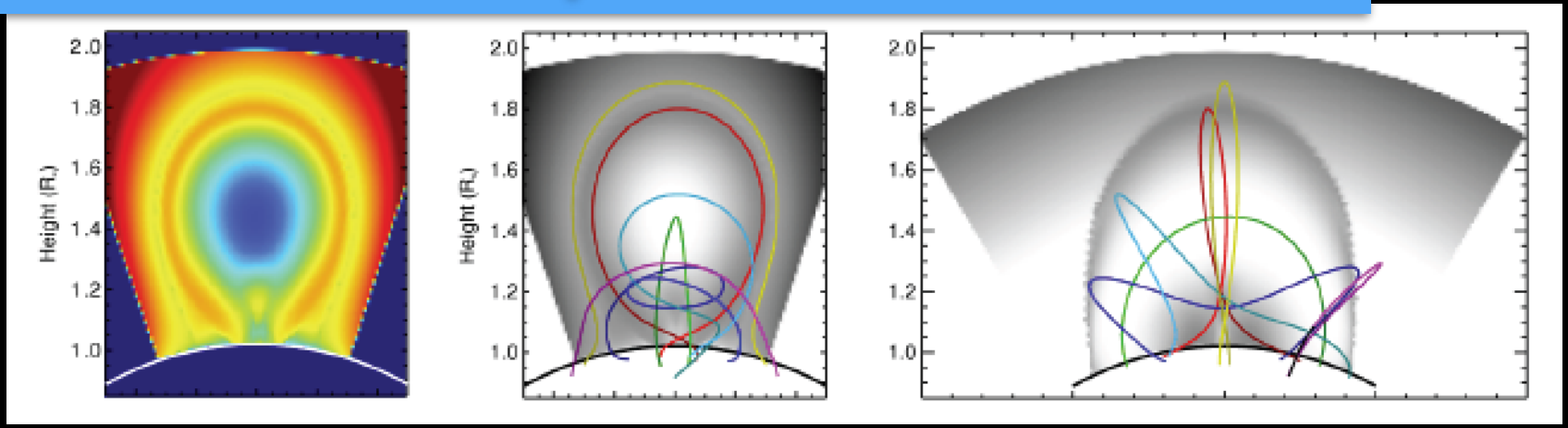
Cavity properties: Density

Interpretation: Flux surface/pressure jump…

$$P_{\text{tube}} + \frac{B^2}{8\pi} = P_{\text{ext}} \quad \rightarrow \quad P_{\text{tube}} = P_{\text{ext}} - \frac{B^2}{8\pi}$$



…short, axial field = density cavity. Hydrostatic model —> 35% depletion *Schmit and Gibson, 2014*

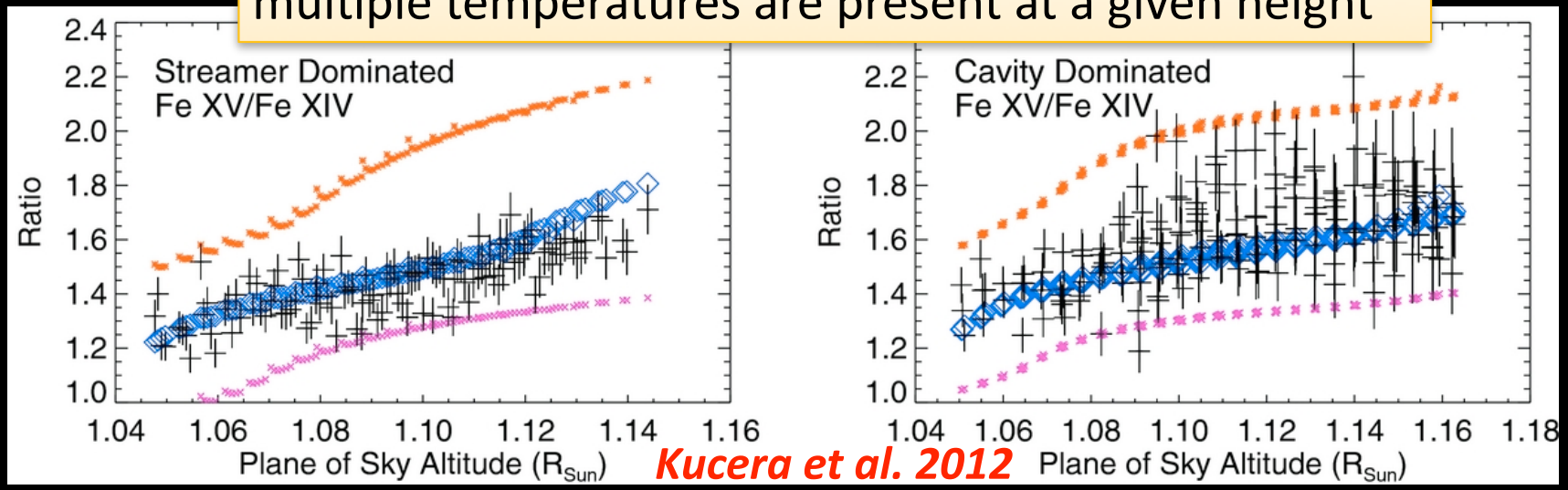


…stability selection effects *Low and Hundhausen, 1995; Gibson, 2014*

Cavity properties: Temperature and Flows

Cavity properties: Temperature and Flows

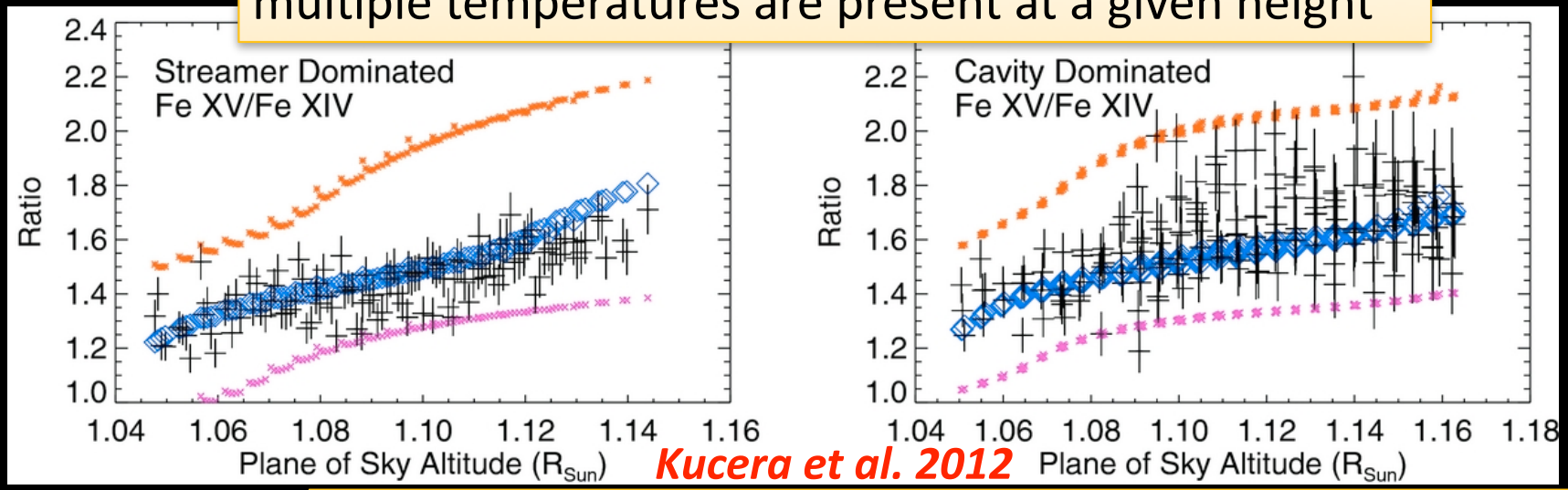
Variability in temperature-sensitive line ratio indicates multiple temperatures are present at a given height



Kucera et al. 2012

Cavity properties: Temperature and Flows

Variability in temperature-sensitive line ratio indicates multiple temperatures are present at a given height

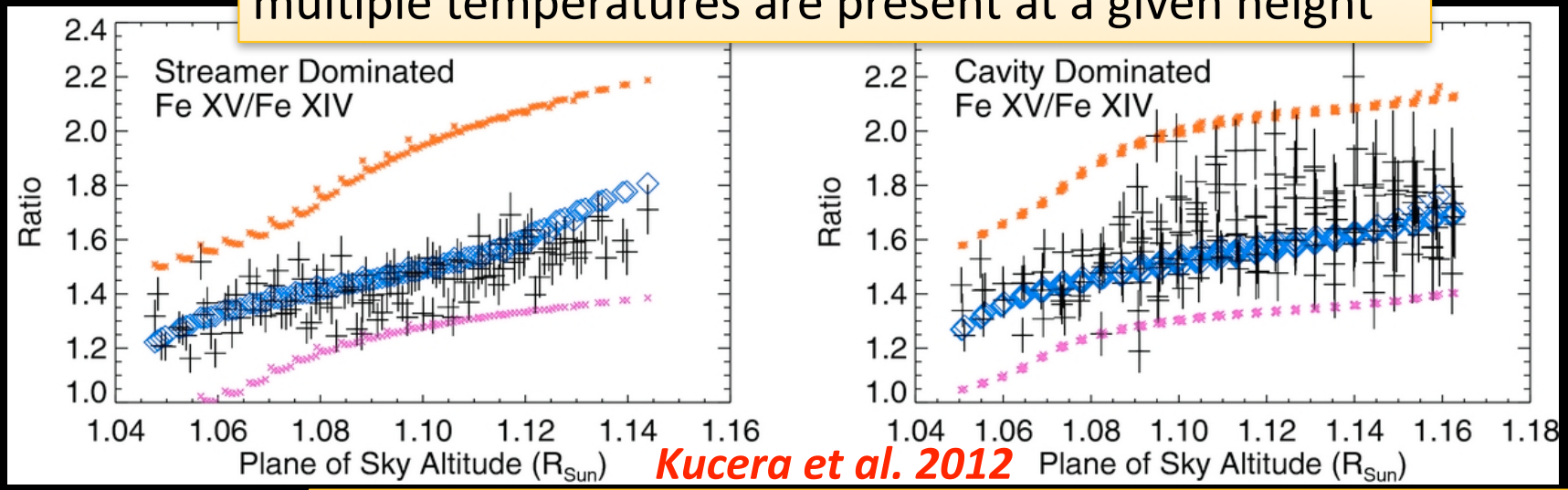


Kucera et al. 2012

Is cavity hotter or cooler than surrounding streamer?

Cavity properties: Temperature and Flows

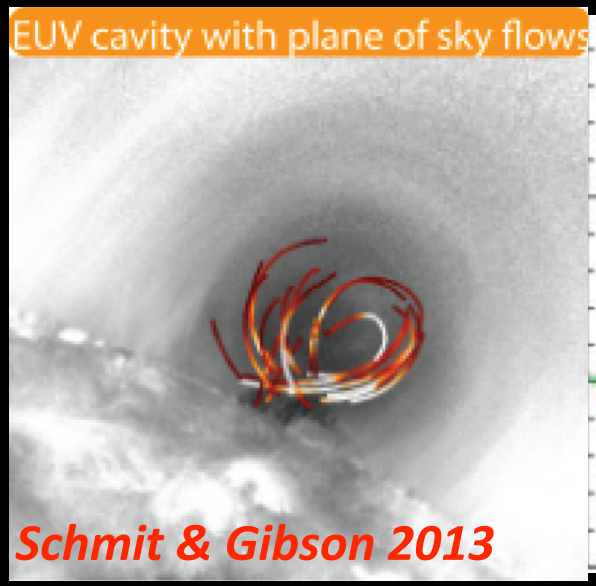
Variability in temperature-sensitive line ratio indicates multiple temperatures are present at a given height

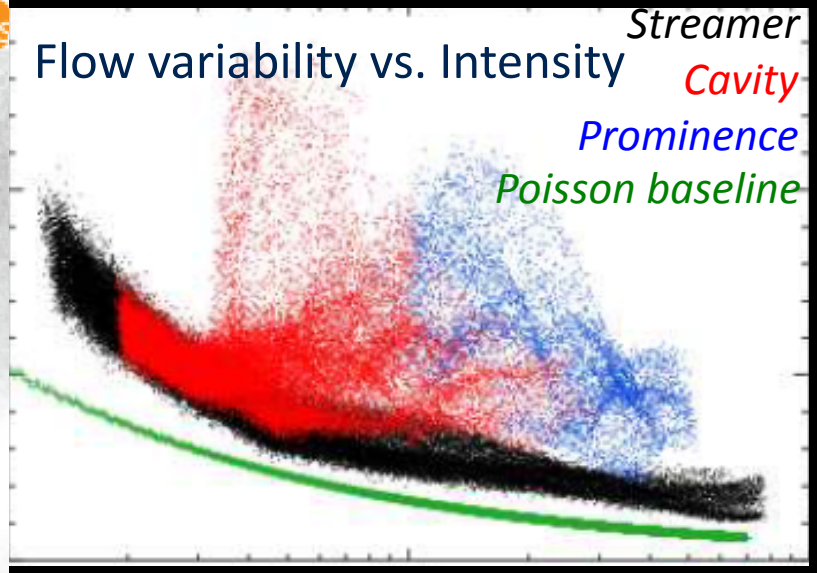


Kucera et al. 2012

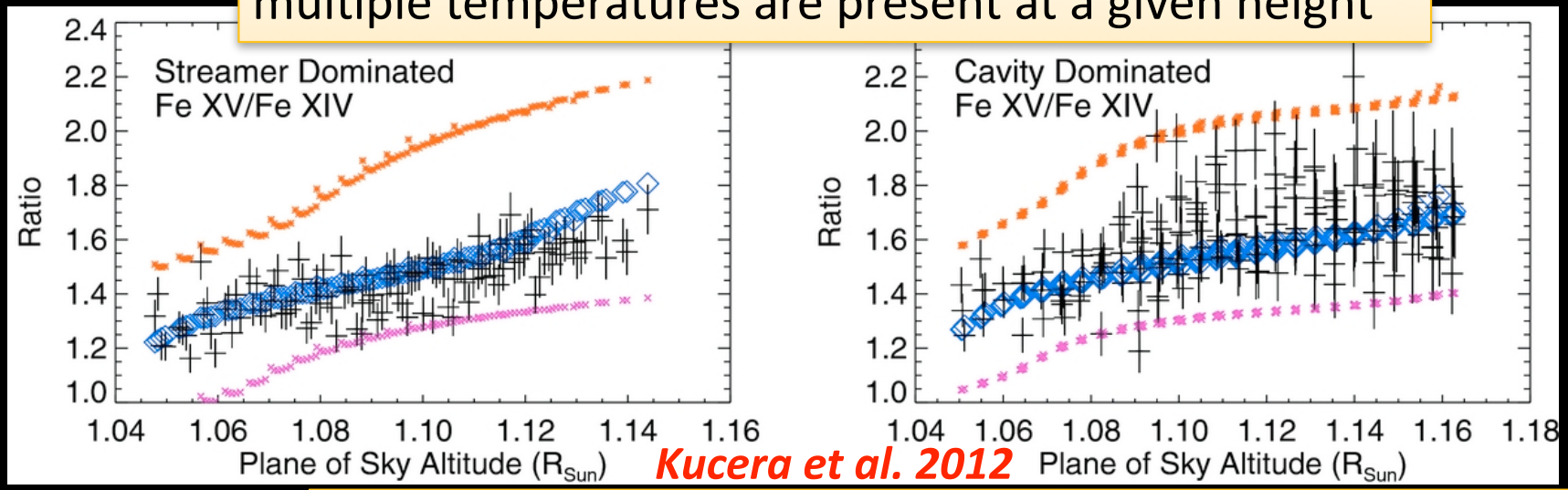
Is cavity hotter or cooler than surrounding streamer? **Yes**

Cavity properties: Temperature and Flows



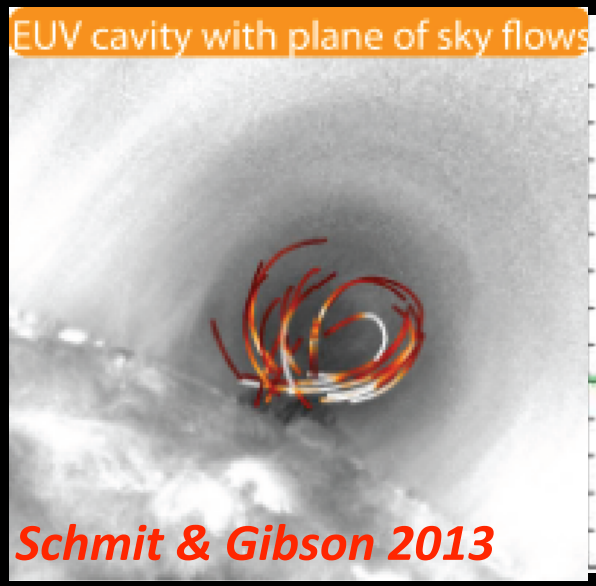


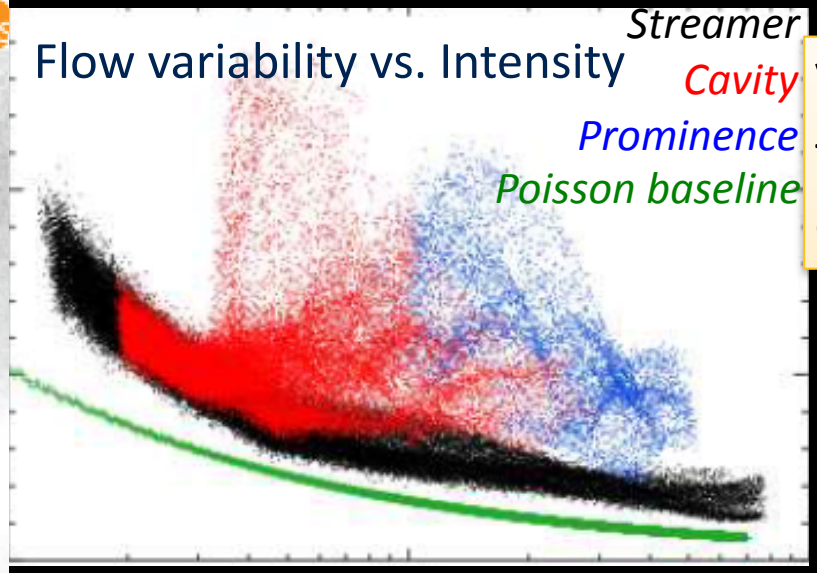
Variability in temperature-sensitive line ratio indicates multiple temperatures are present at a given height



Is cavity hotter or cooler than surrounding streamer? **Yes**

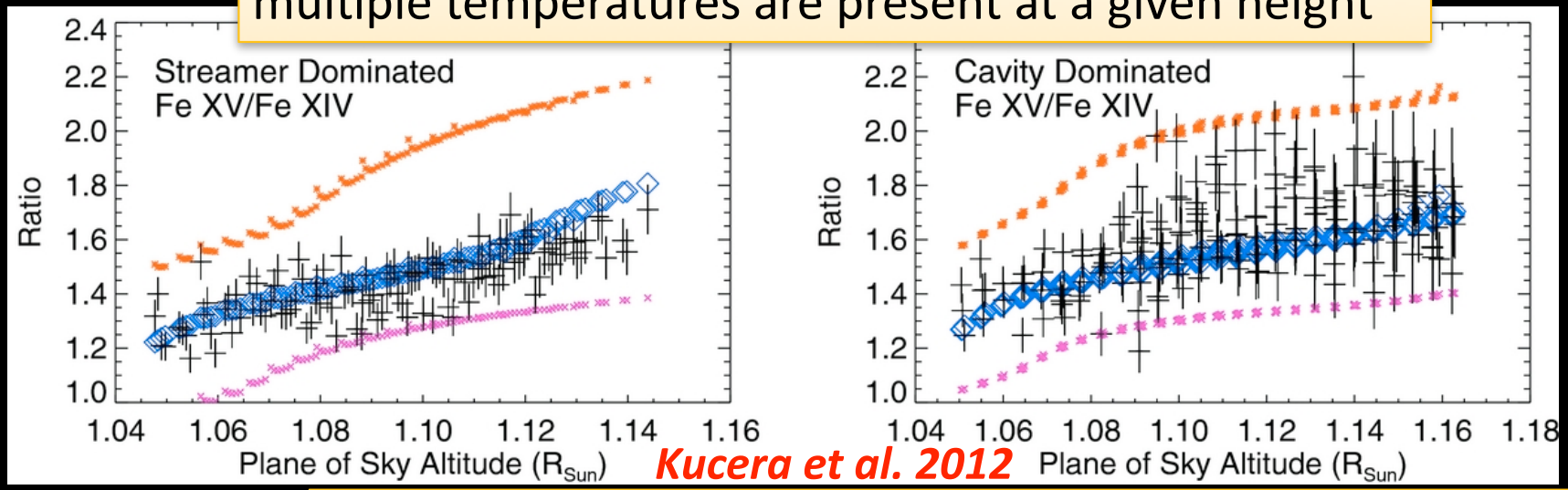
Cavity properties: Temperature and Flows





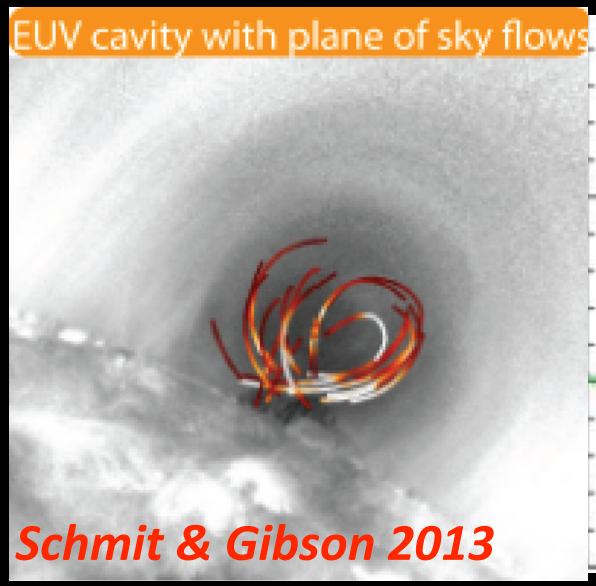
Variability of plane-of-sky flows is likewise enhanced in cavity relative to streamer.

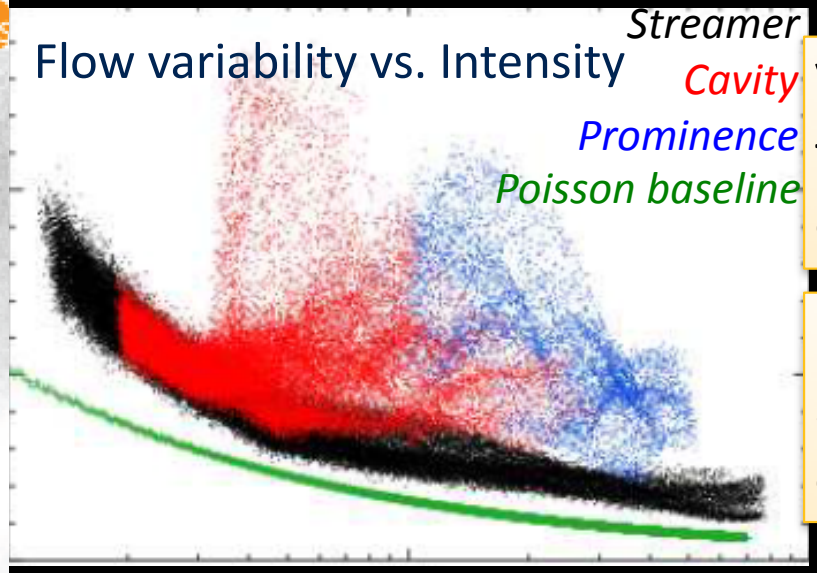
Variability in temperature-sensitive line ratio indicates multiple temperatures are present at a given height



Is cavity hotter or cooler than surrounding streamer? Yes

Cavity properties: Temperature and Flows

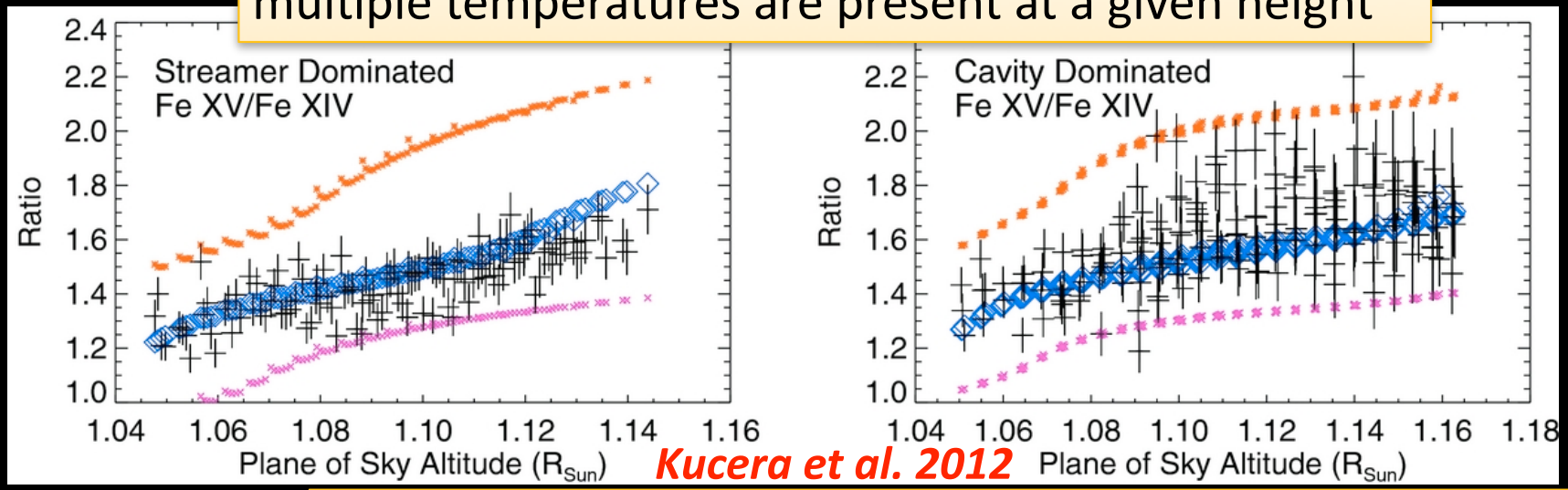




Variability of plane-of-sky flows is likewise enhanced in cavity relative to streamer.

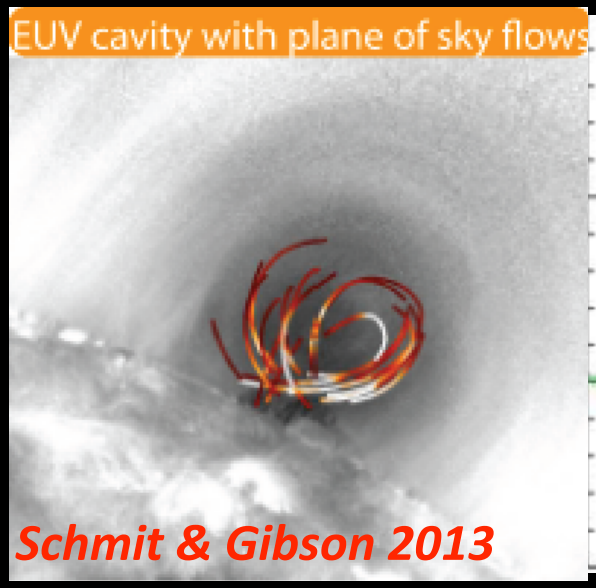
Cavity and prominence flows are spatially and temporally correlated.

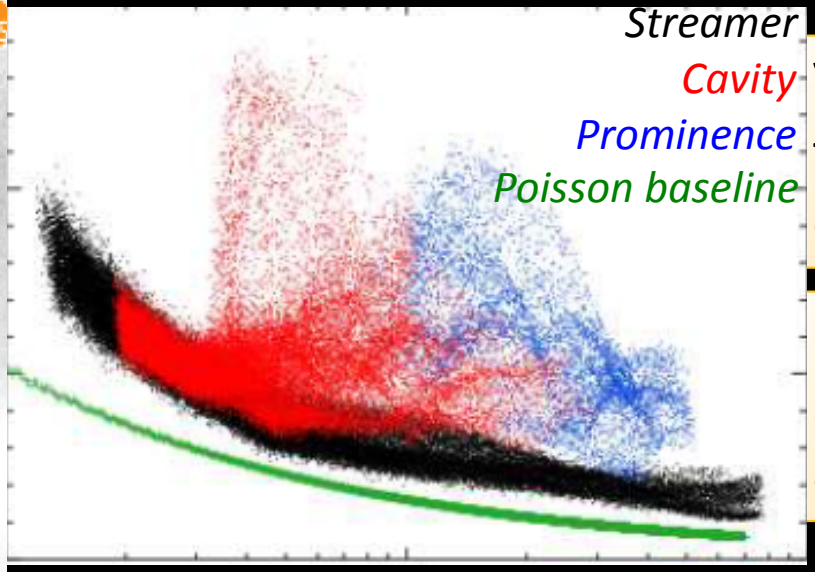
Variability in temperature-sensitive line ratio indicates multiple temperatures are present at a given height



Is cavity hotter or cooler than surrounding streamer? **Yes**

Cavity properties: Temperature and Flows

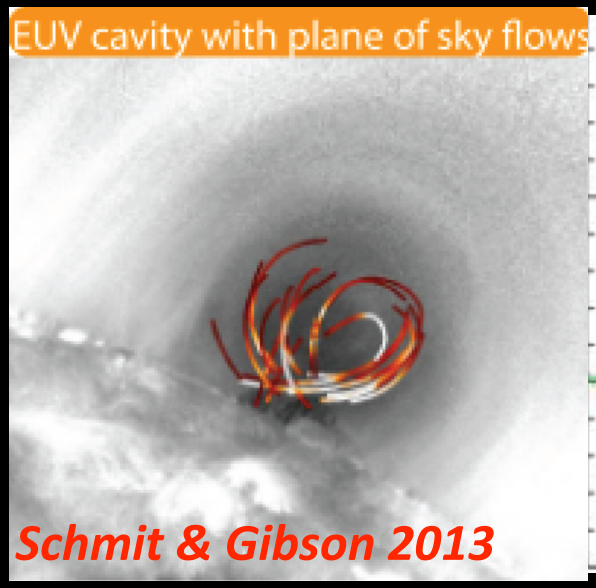


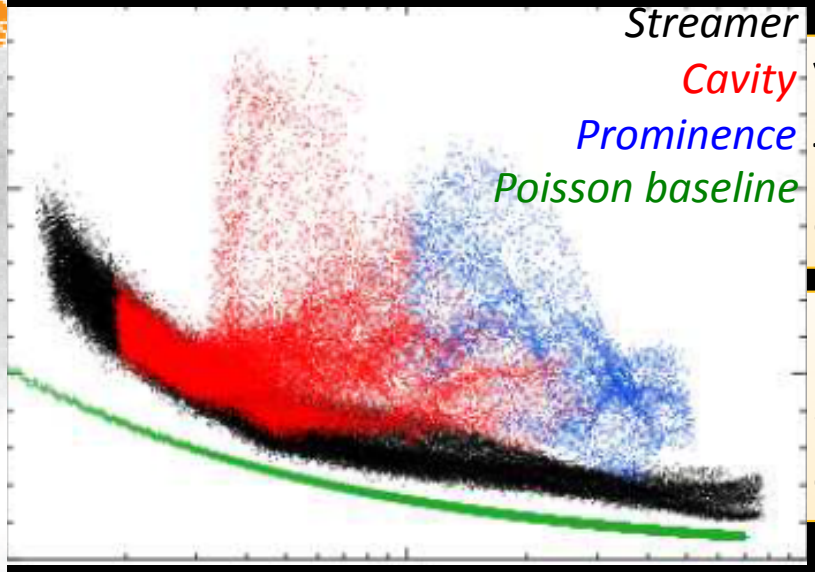


Variability of plane-of-sky flows is likewise enhanced in cavity relative to streamer.

Cavity and prominence flows are spatially and temporally correlated.

Cavity properties: Temperature and Flows



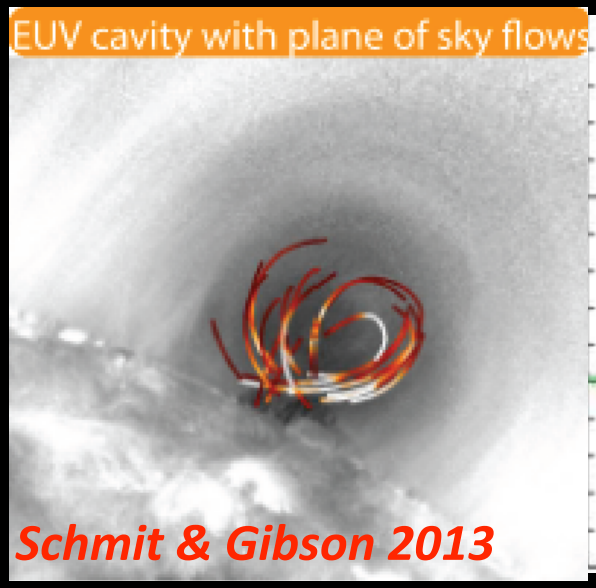


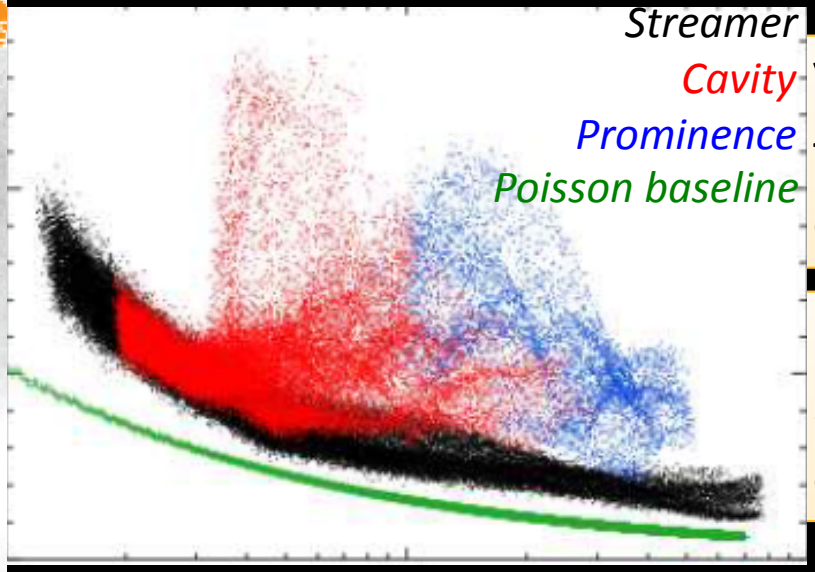
Variability of plane-of-sky flows is likewise enhanced in cavity relative to streamer.

Cavity and prominence flows are spatially and temporally correlated.

Interpretation: Thermal nonequilibrium. Consistent with dynamic observations of EUV brightenings (horns) followed by formation of prominence. ***Schmit et al 2013***

Cavity properties: Temperature and Flows

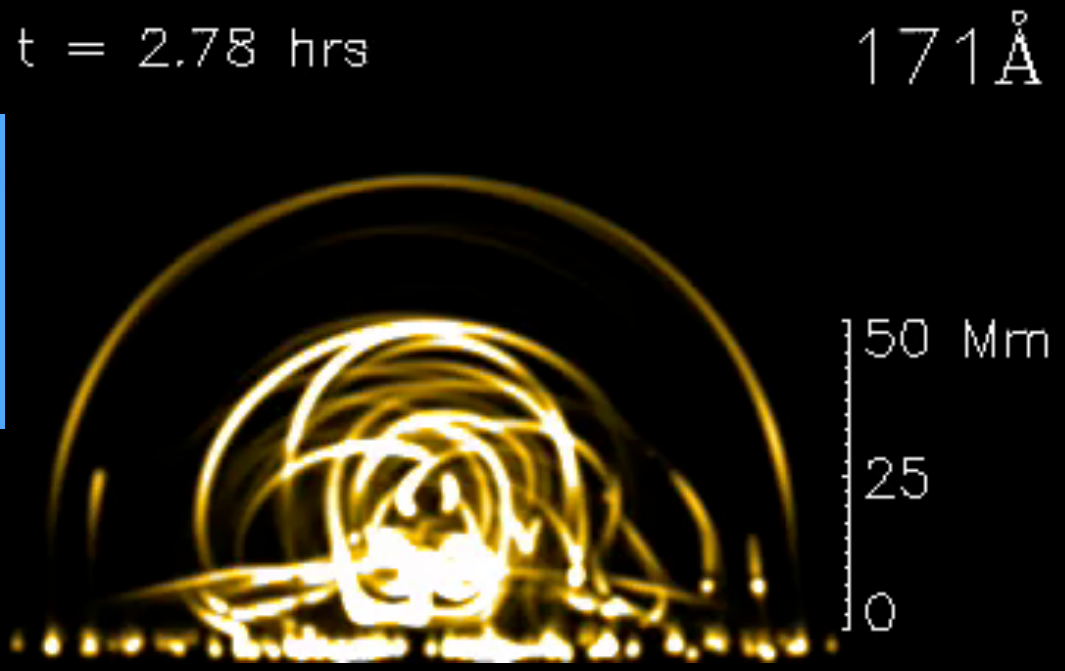




Variability of plane-of-sky flows is likewise enhanced in cavity relative to streamer.

Cavity and prominence flows are spatially and temporally correlated.

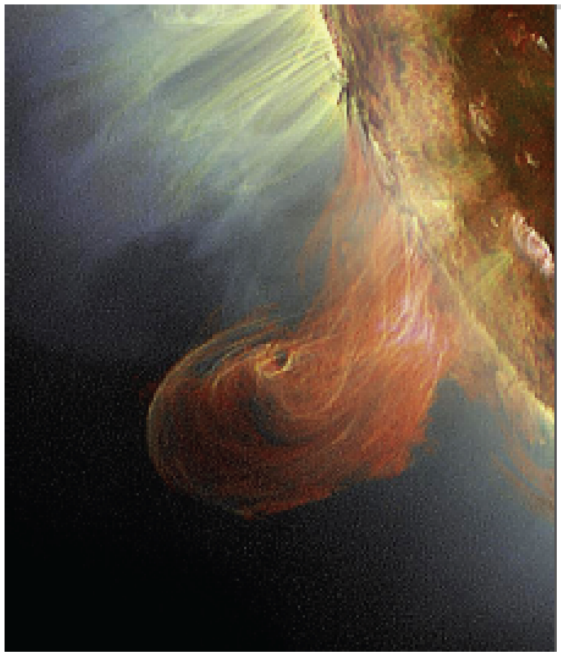
Interpretation: **Thermal nonequilibrium.** Consistent with dynamic observations of EUV brightenings (horns) followed by formation of prominence. ***Schmit et al 2013***

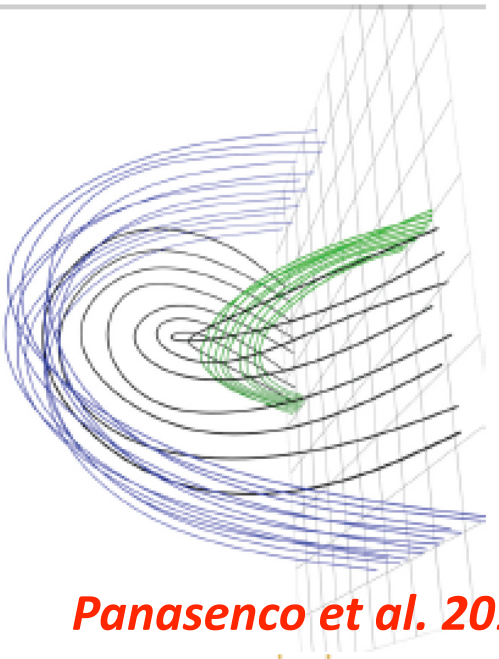


Luna et al., 2012

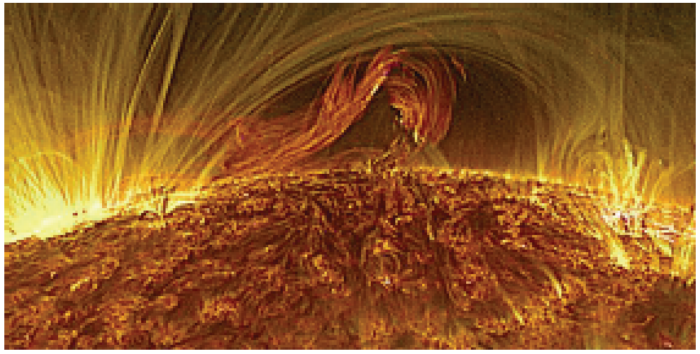
Cavity properties: Flows (swirling)

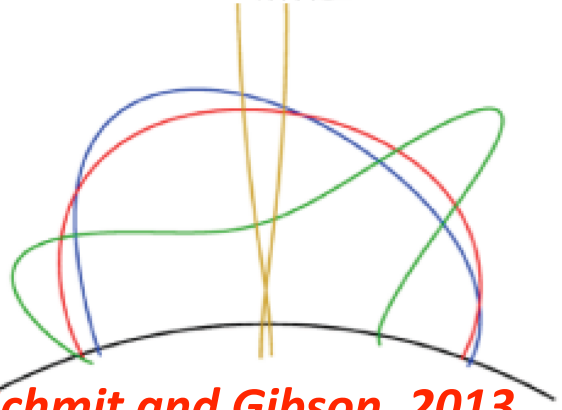
Cavity properties: Flows (swirling)





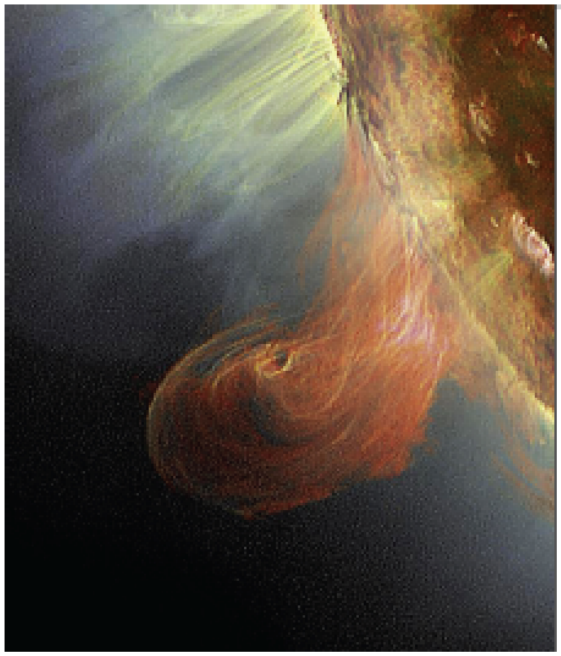
Panasenco et al. 2014

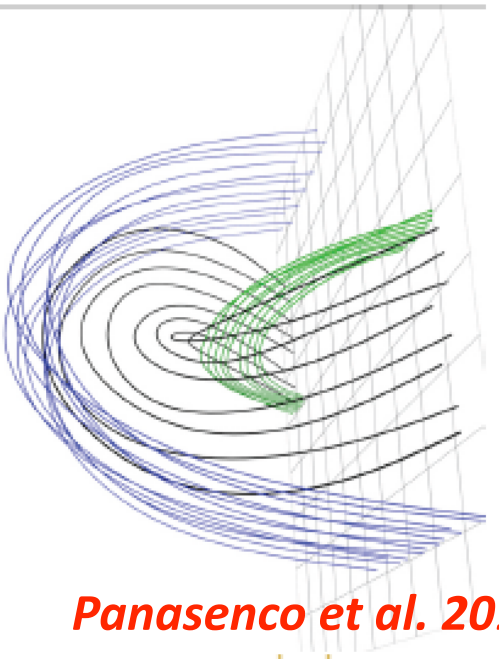




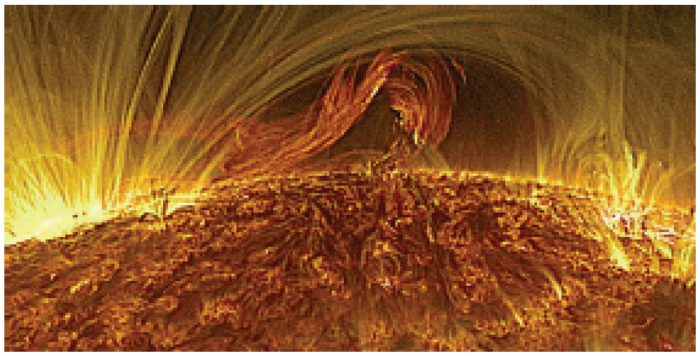
Schmit and Gibson, 2013

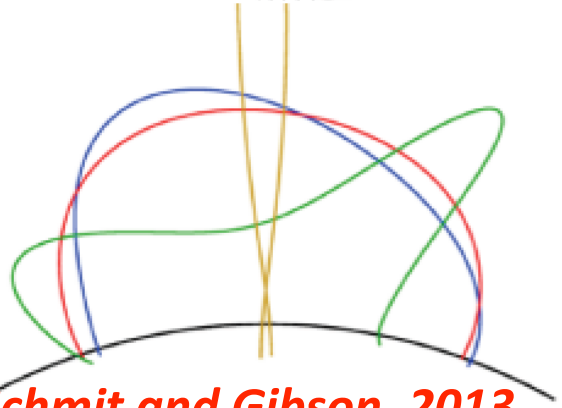
Cavity properties: Flows (swirling)





Panasenco et al. 2014





Schmit and Gibson, 2013

Interpretation: **Flow along field lines.** Both flux rope and sheared arcade model have field lines with writhe — can't distinguish without establishing whether writhed field line ***wraps around axis***.

Cavity properties: Flows (Bulls-eye!)

Cavity properties: Flows (Bulls-eye!)

Interpretion: Toroidal flux surfaces within a flux rope.
Field lines wrapping around axis.

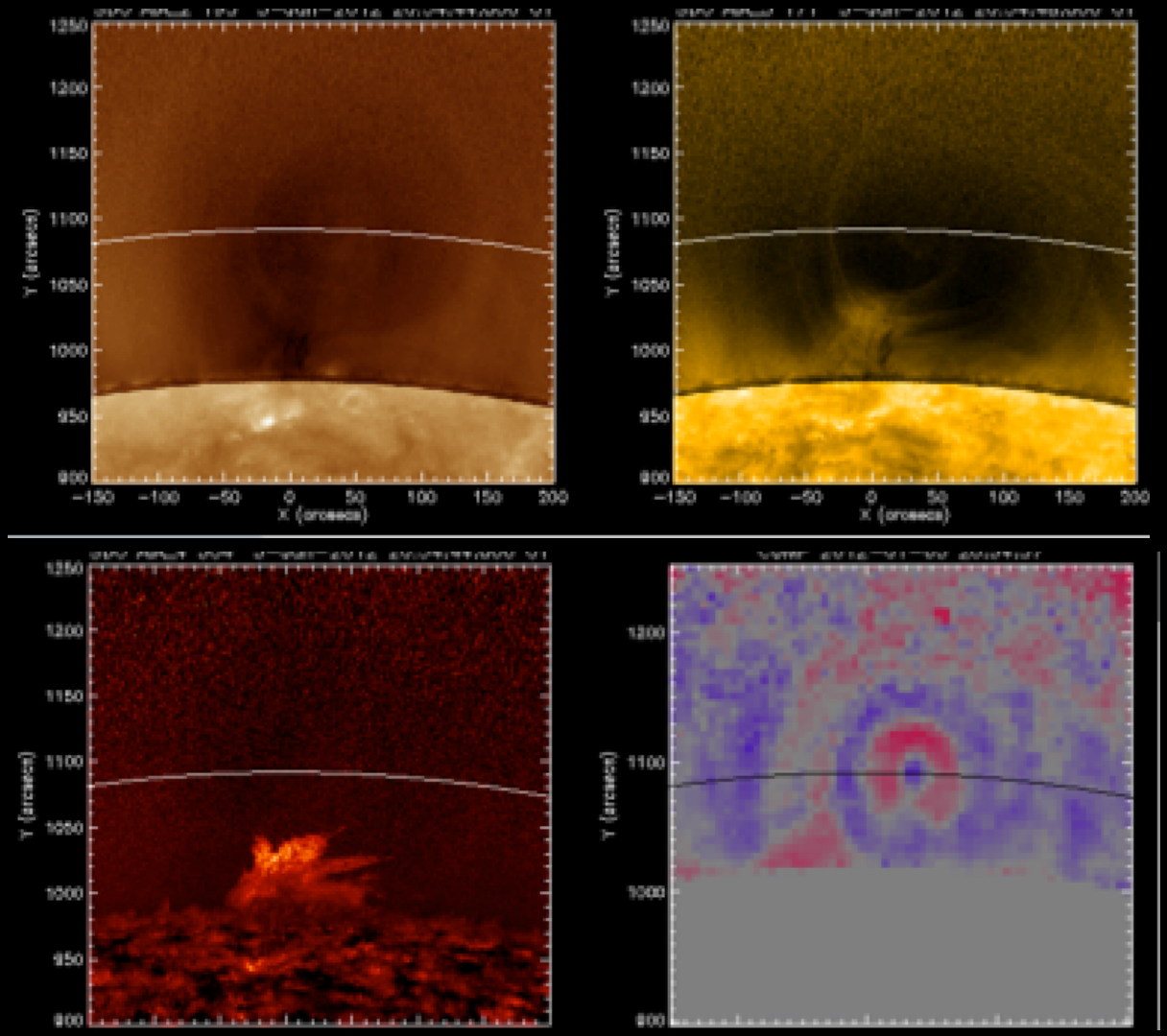
Cavity properties: Flows (Bulls-eye!)

First noted by D. Tripathi in Hinode data

Interpretion: Toroidal flux surfaces within a flux rope.
Field lines wrapping around axis.

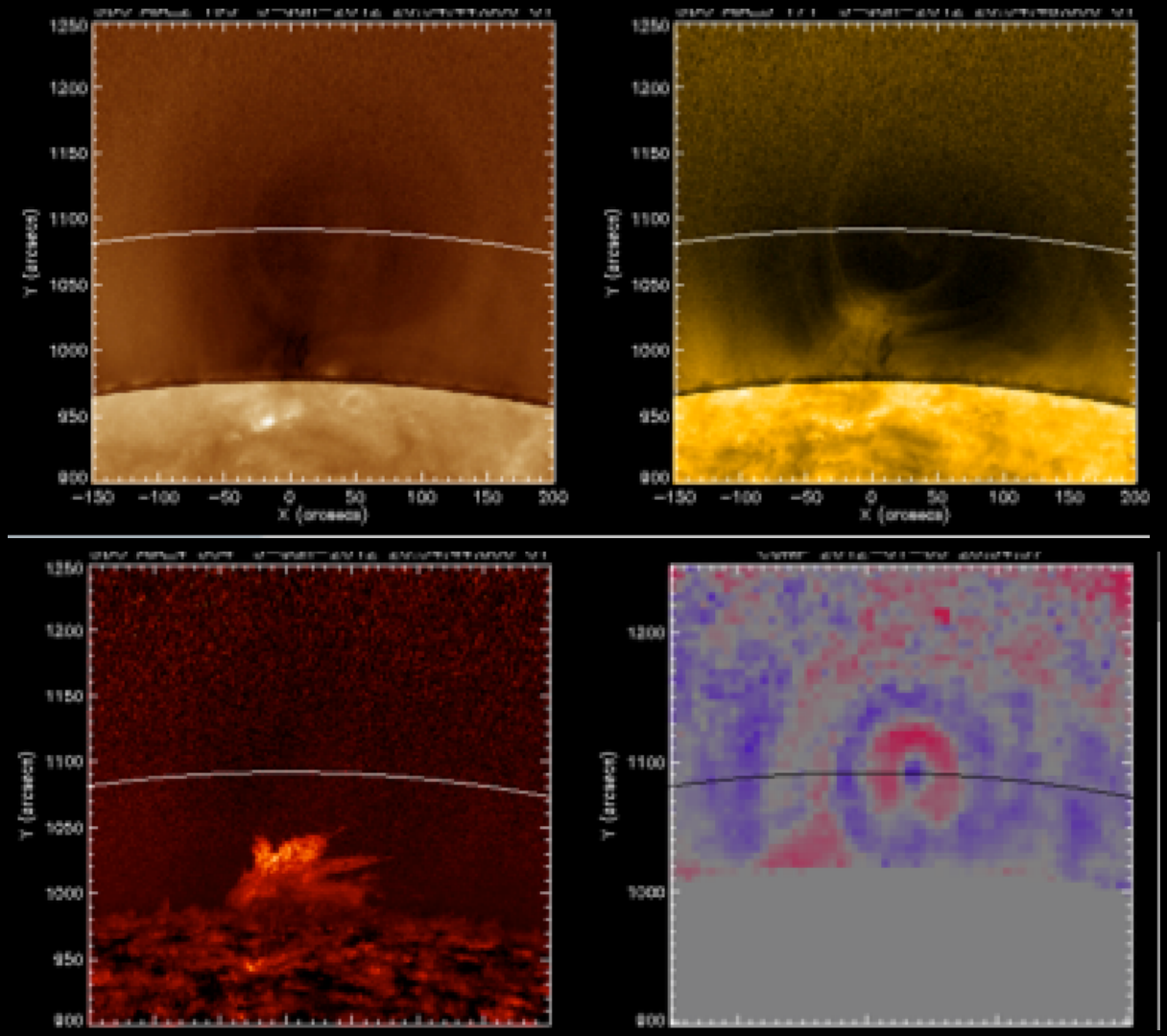
Lollypops (Cavity substructure)

Lollypops (Cavity substructure)



Courtesy U. Bak-Steslicka

Lollypops (Cavity substructure)

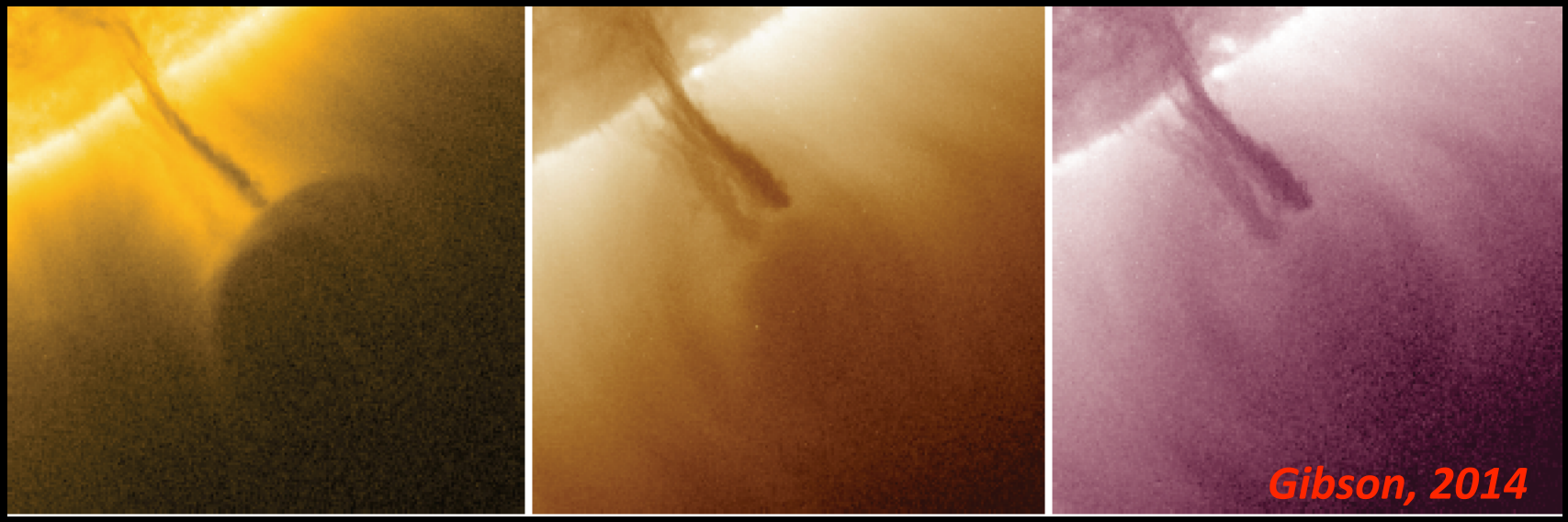


Courtesy U. Bak-Steslicka

LOS flows lie above prominence and within cavity

Lollypops (Cavity substructure)

Horn-like structures and central voids, above prominence and within cavity



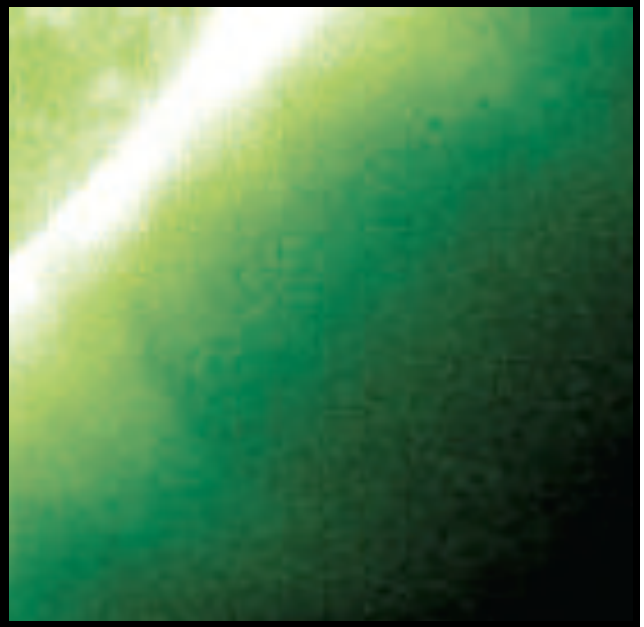
Lollypops (Cavity substructure)

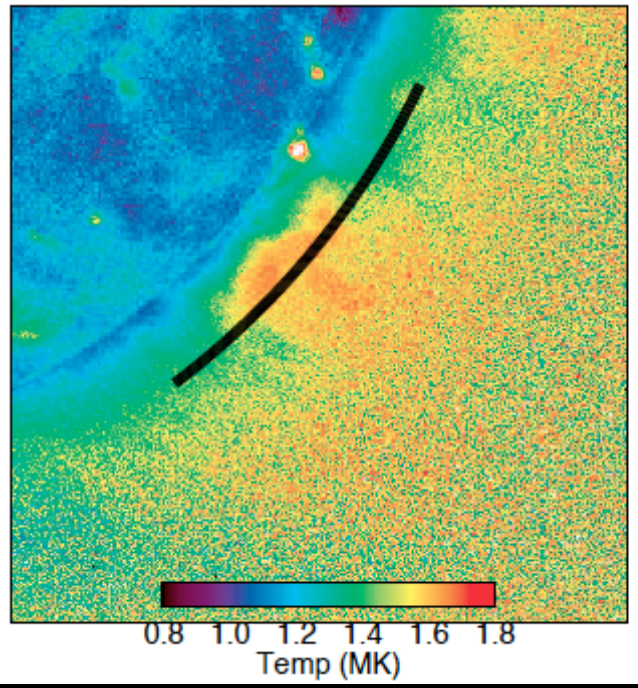
Lollypops (Cavity substructure)

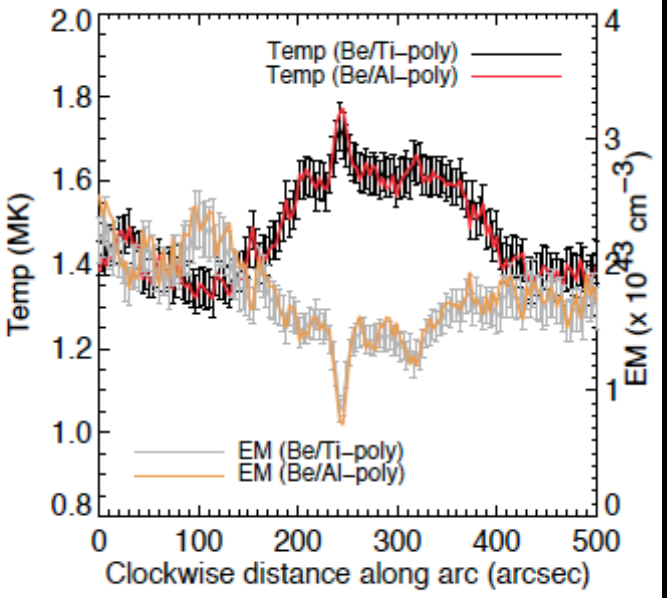
High-temperature soft-X-ray cores

Lollypops (Cavity substructure)

High-temperature soft-X-ray cores



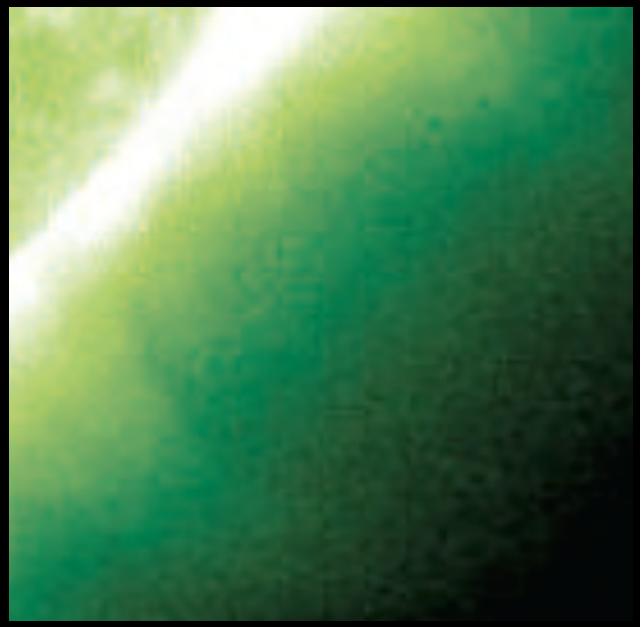


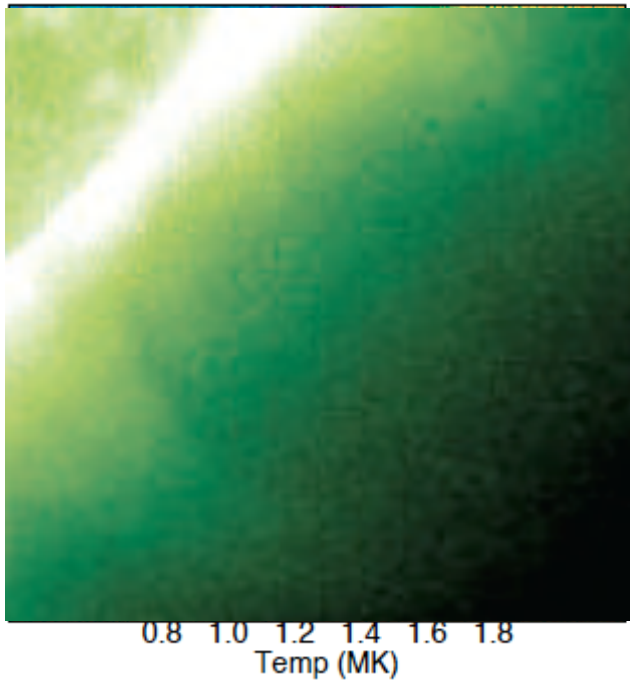


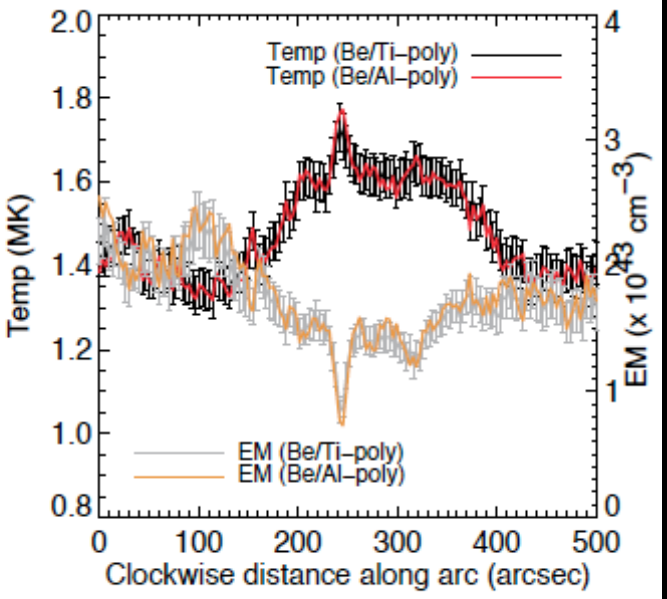
Reeves et al., 2012

Lollypops (Cavity substructure)

High-temperature soft-X-ray cores



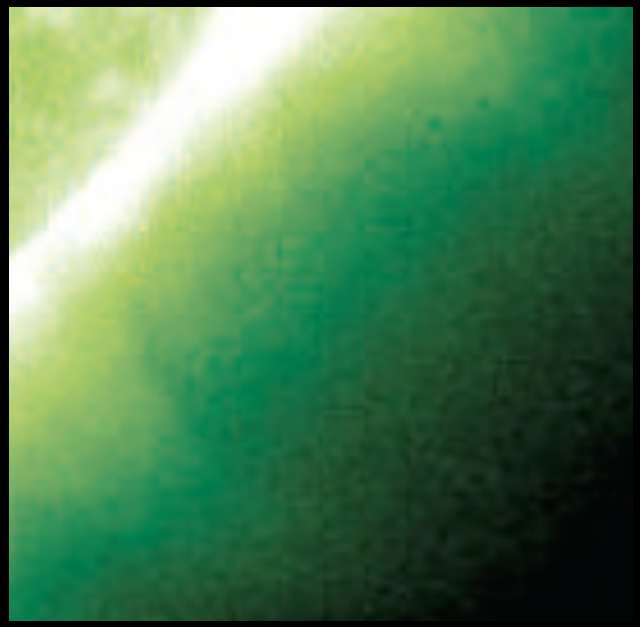


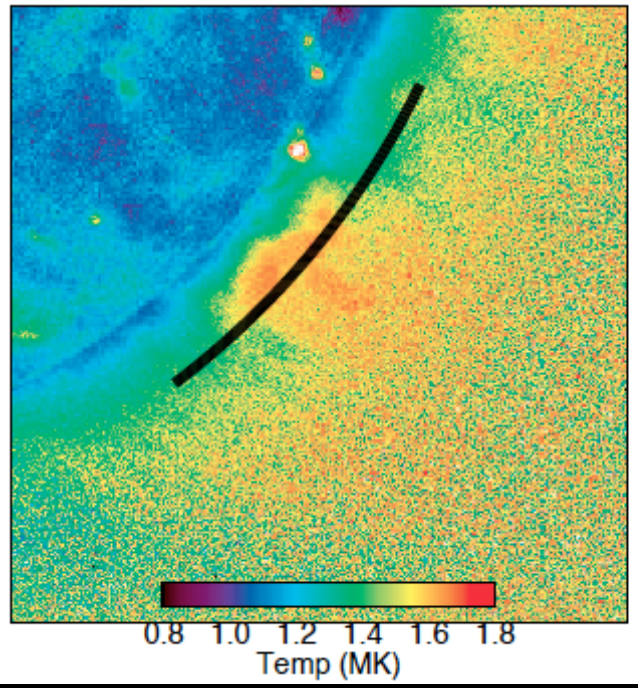


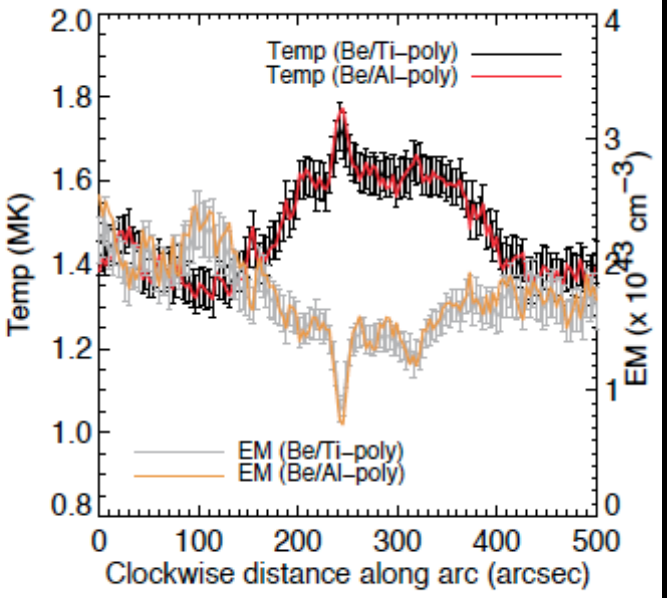
Reeves et al., 2012

Lollypops (Cavity substructure)

High-temperature soft-X-ray cores



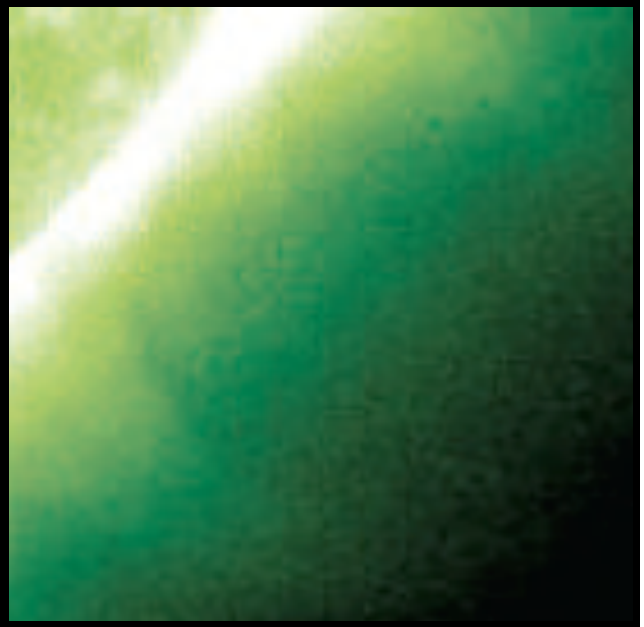




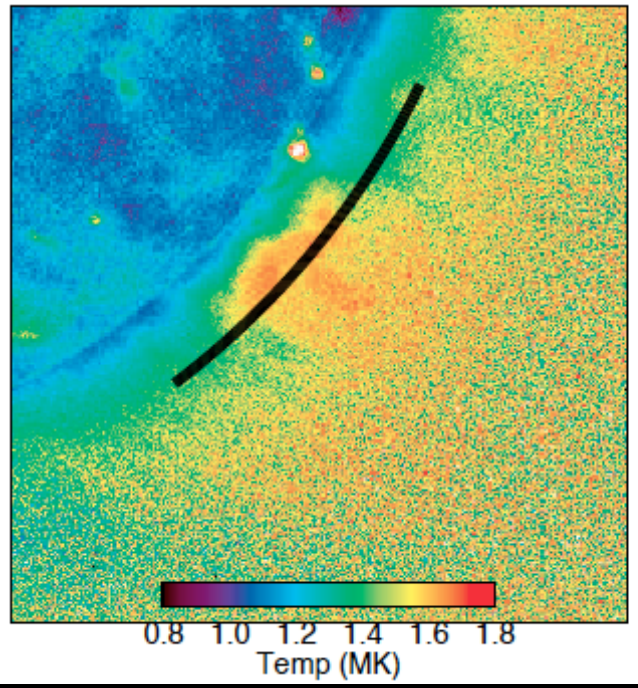
Reeves et al., 2012

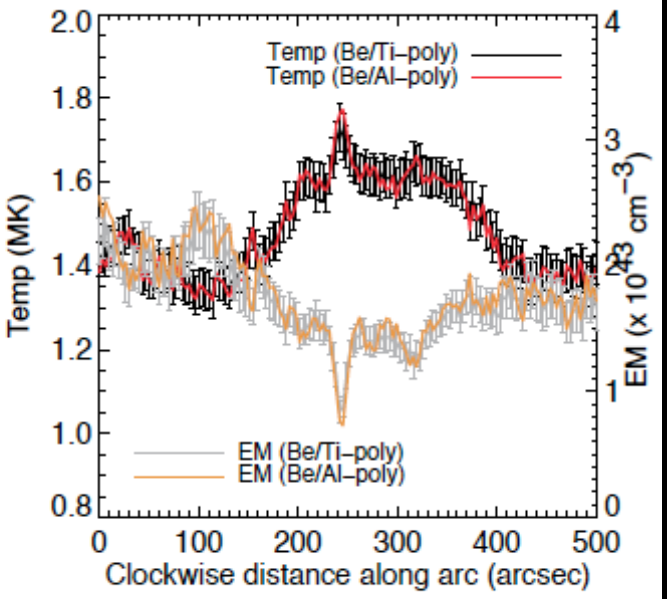
Lollypops (Cavity substructure)

High-temperature soft-X-ray cores



see also Habbal et al 2007



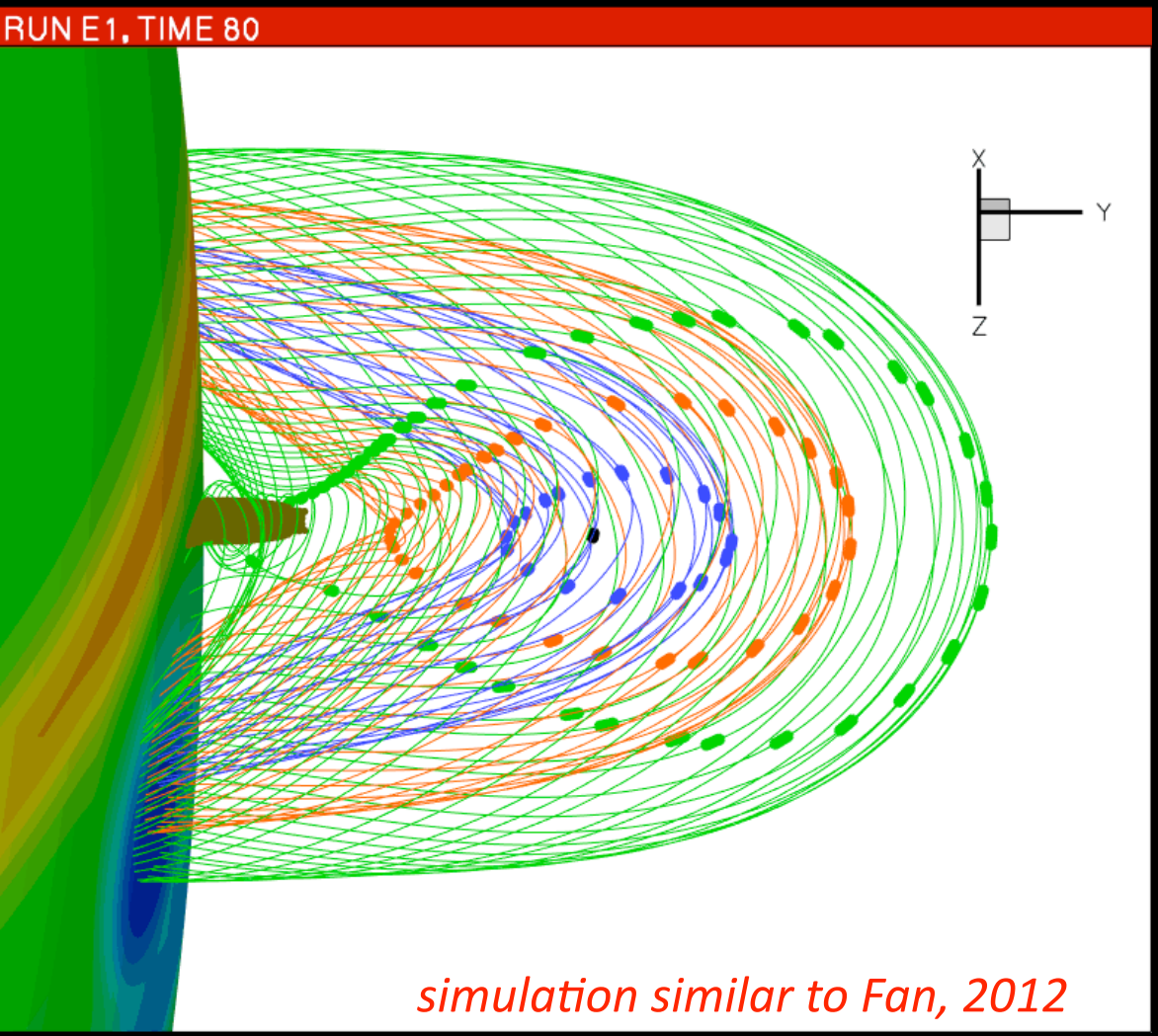


Reeves et al., 2012

Hudson et al. 1999

Lollypops (Cavity substructure)

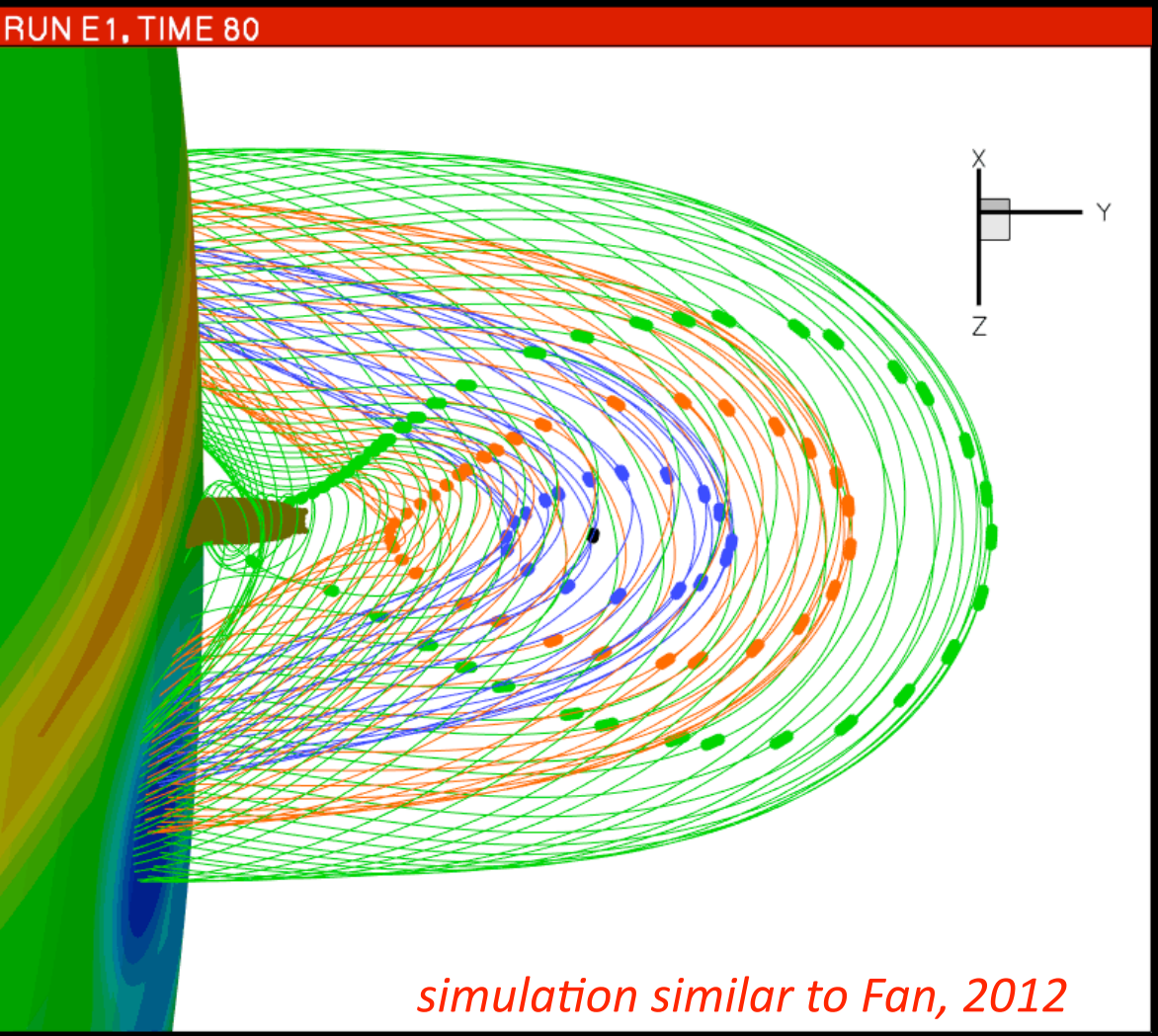
Interpretion: Dipped vs. non-dipped field lines



simulation similar to Fan, 2012

Lollypops (Cavity substructure)

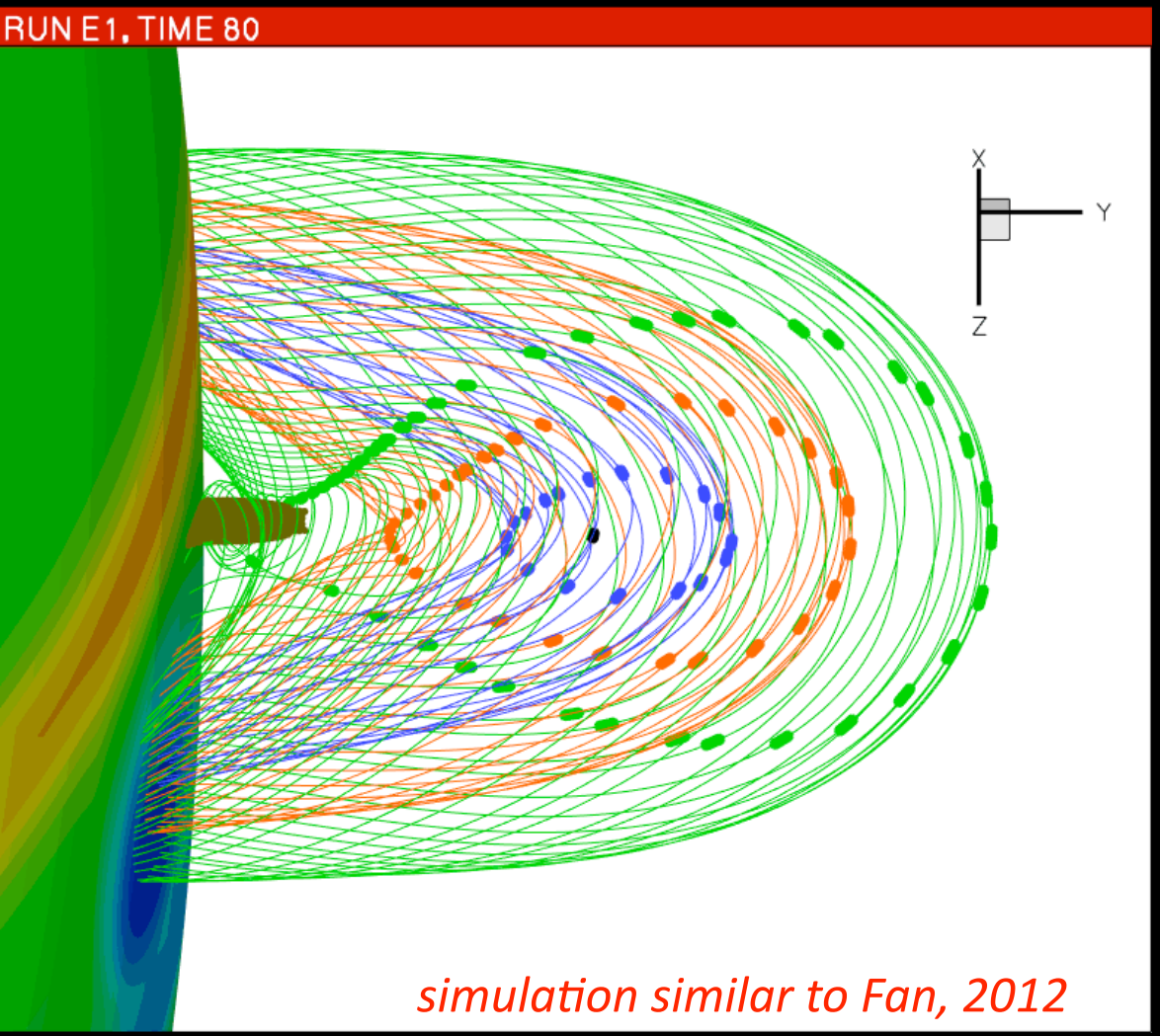
Interpretion: Dipped vs. non-dipped field lines



simulation similar to Fan, 2012

Lollypops (Cavity substructure)

Interpretion: Dipped vs. non-dipped field lines



simulation similar to Fan, 2012

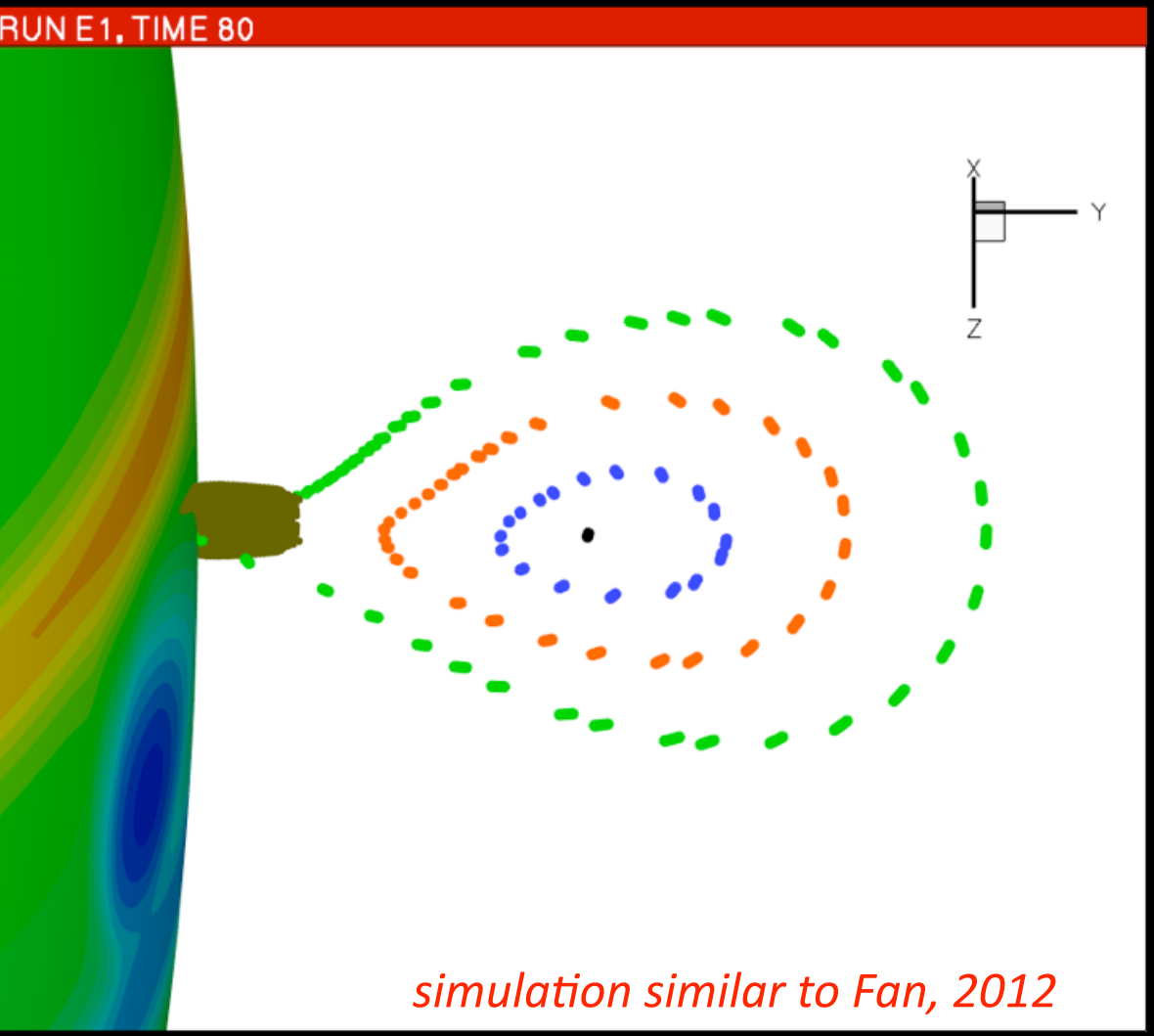
Because it arches upwards, most of the field lines do not have dips that can support prominence mass against gravity

If we fill dips up to a prominence thermal scale height - would form a sheet-like prominence (brown)

Main part of cavity (nondipped field) above prominence (lollypop),

Lollypops (Cavity substructure)

Interpretion: Dipped vs. non-dipped field lines



simulation similar to Fan, 2012

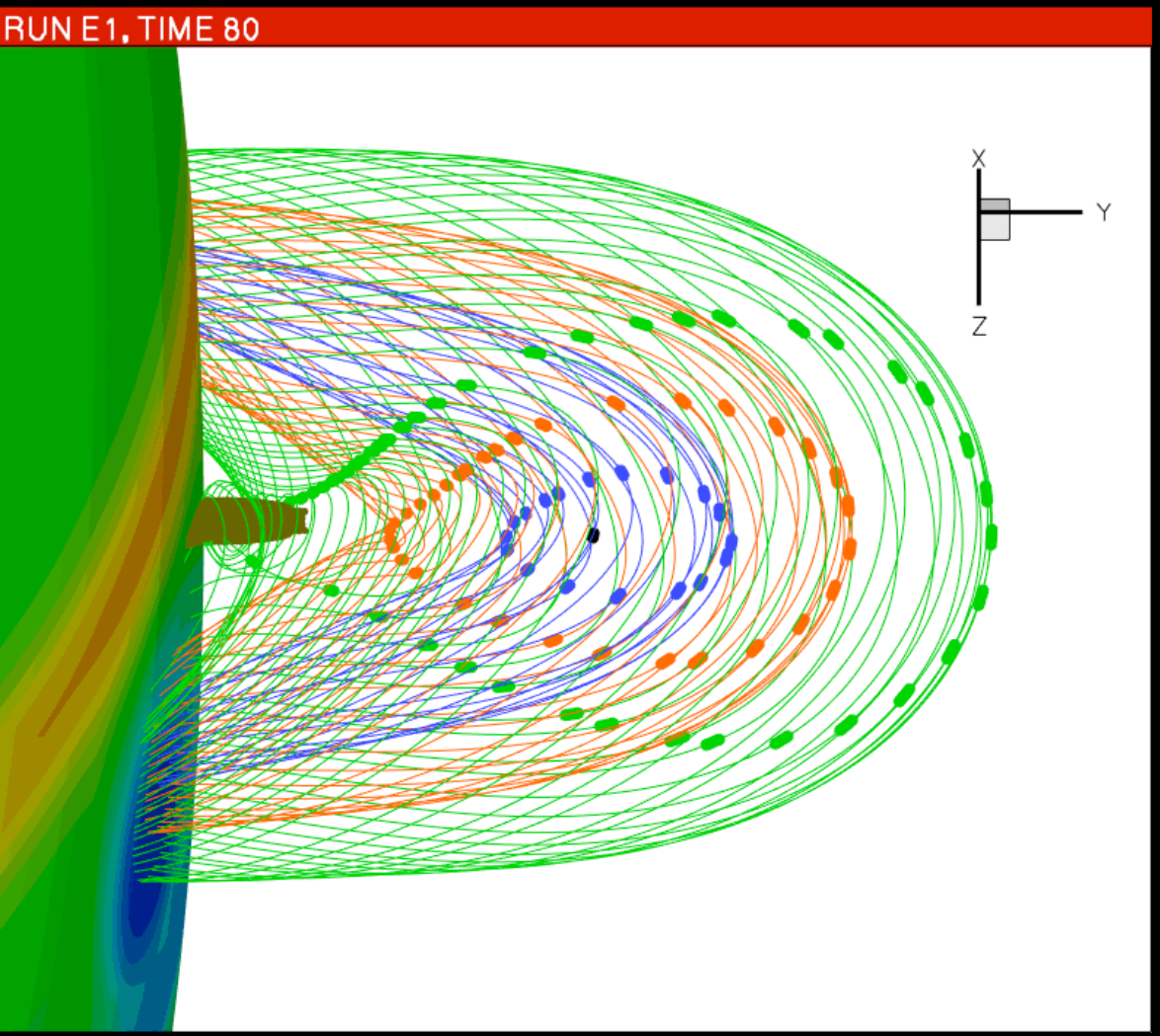
Because it arches upwards, most of the field lines do not have dips that can support prominence mass against gravity

If we fill dips up to a prominence thermal scale height - would form a sheet-like prominence (brown)

Main part of cavity (nondipped field) above prominence (lollypop),

Lollypops (Cavity substructure)

Interpretion: Dipped vs. non-dipped field lines



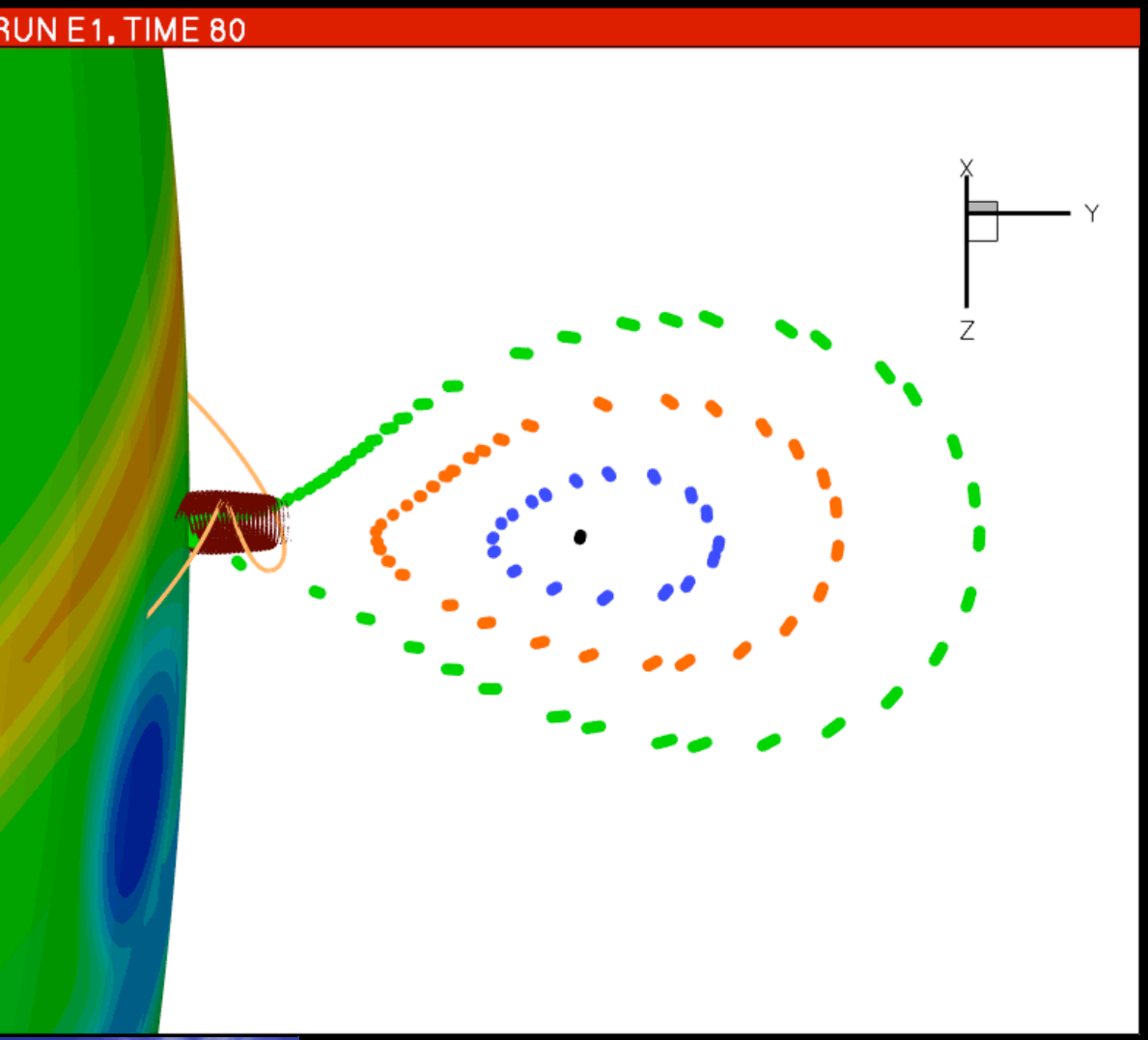
Flux rope winds just over one full turn

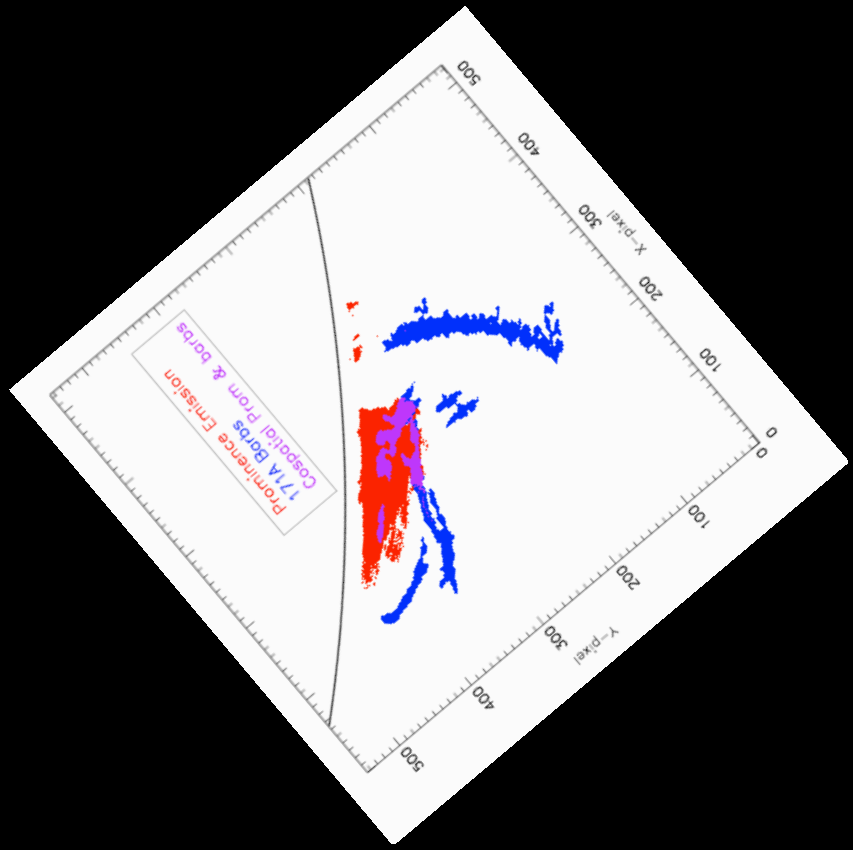
Outer field lines (green) are dipped, longer - location of TNE —> dense, variable

The inner field lines (orange/blue) are undipped, shorter, and fill most of the rope volume

Lollypops (Cavity substructure)

Interpretion: Dipped vs. non-dipped field lines



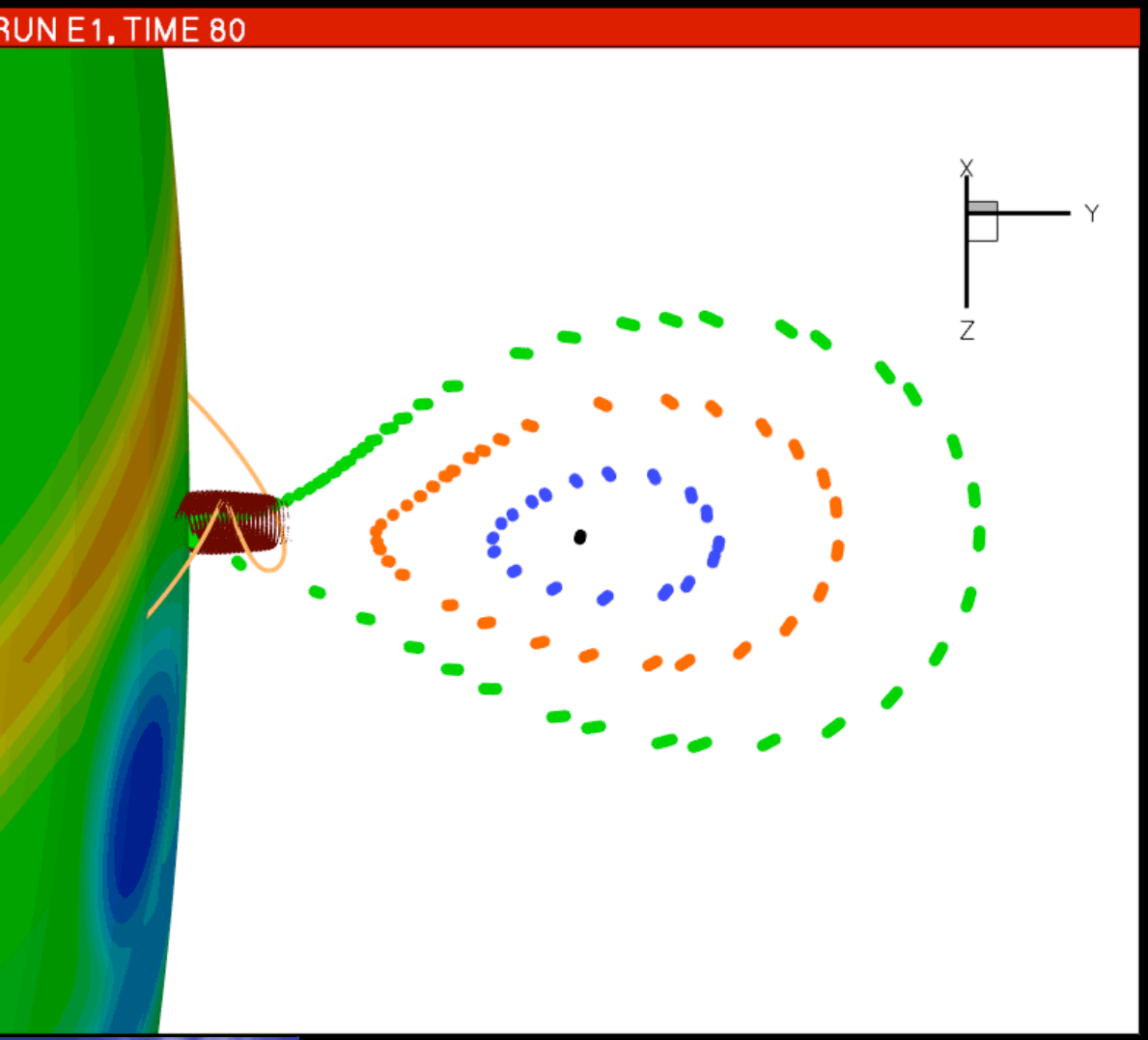


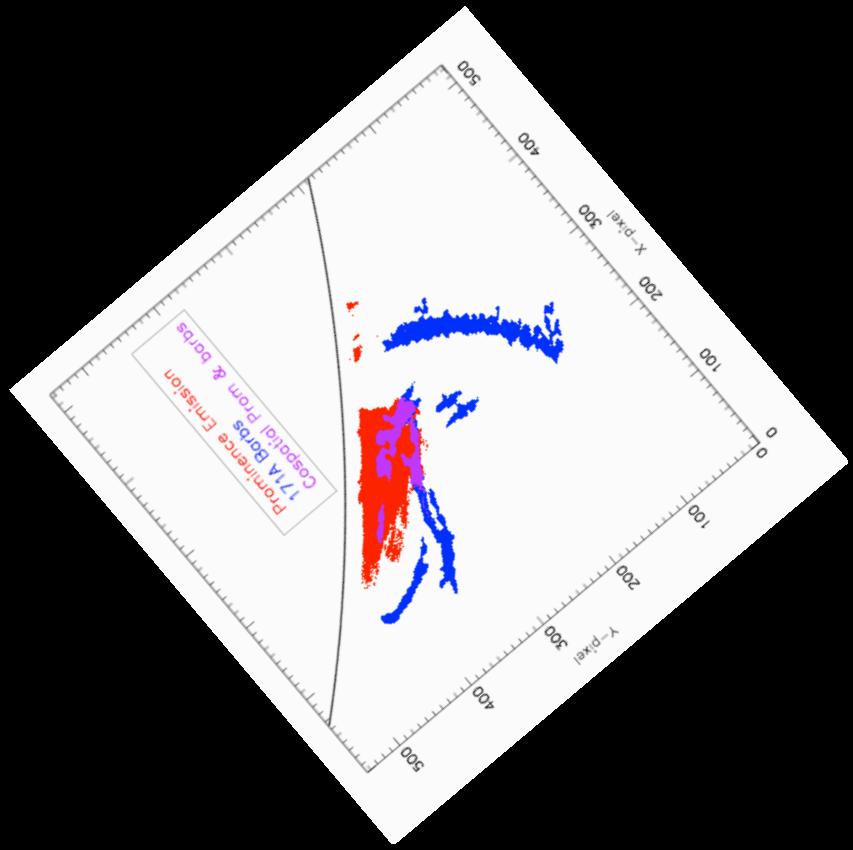
Variable flows and temperature would project into **but not fill** the flux-rope cavity volume

Schmit et al 2013

Lollypops (Cavity substructure)

Interpretion: Dipped vs. non-dipped field lines



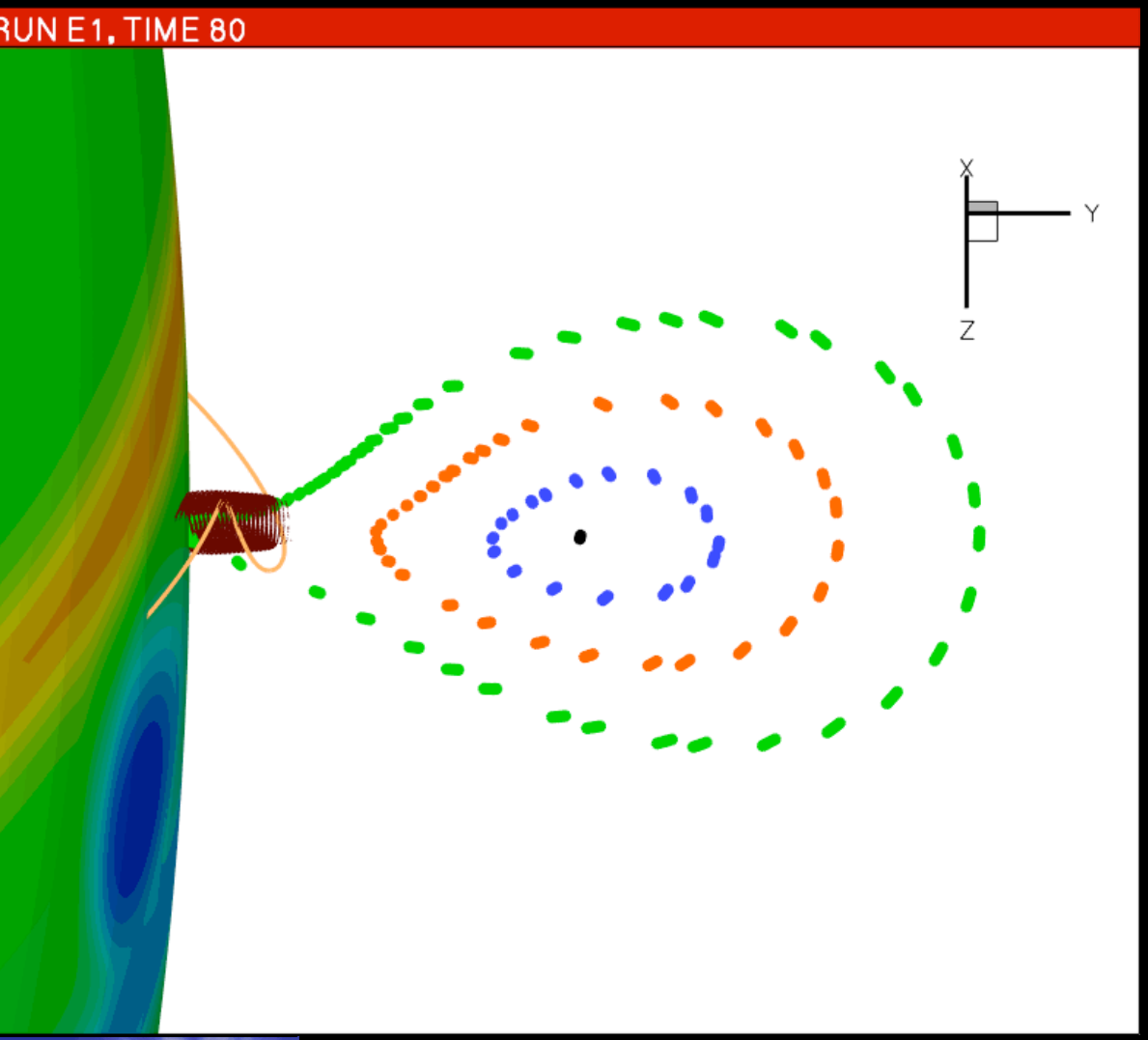


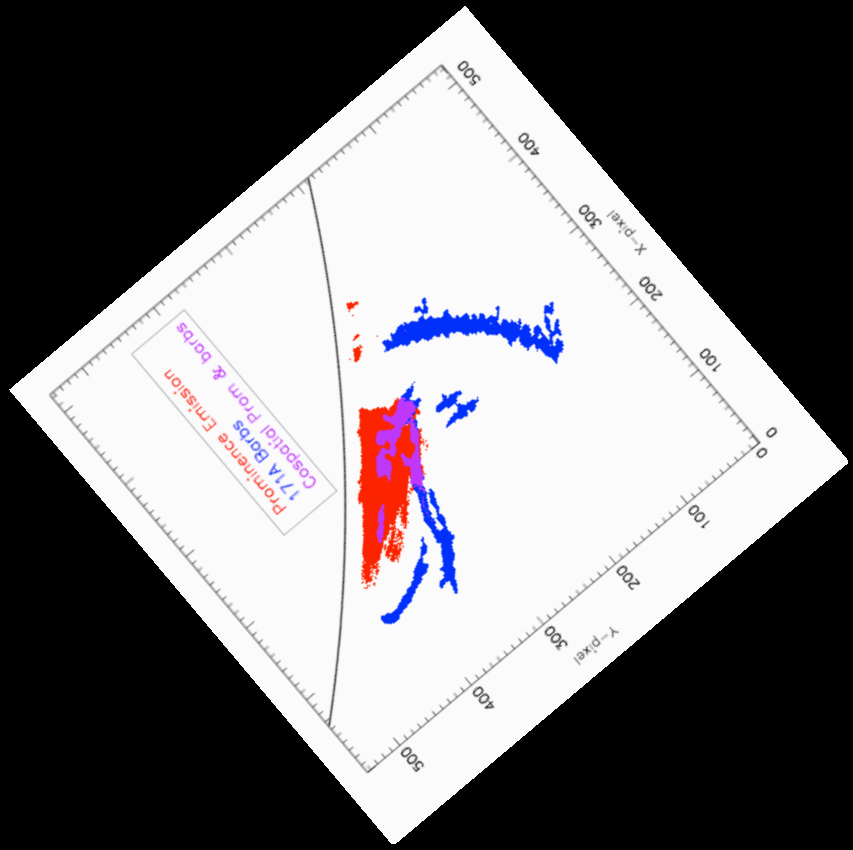
Variable flows and temperature would project into **but not fill** the flux-rope cavity volume

Schmit et al 2013

Lollypops (Cavity substructure)

Interpretion: Dipped vs. non-dipped field lines

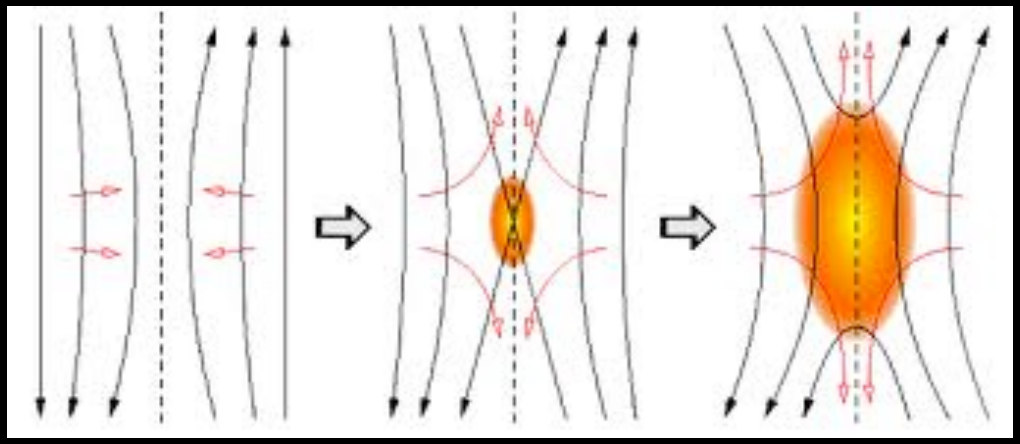




Variable flows and temperature would project into **but not fill** the flux-rope cavity volume

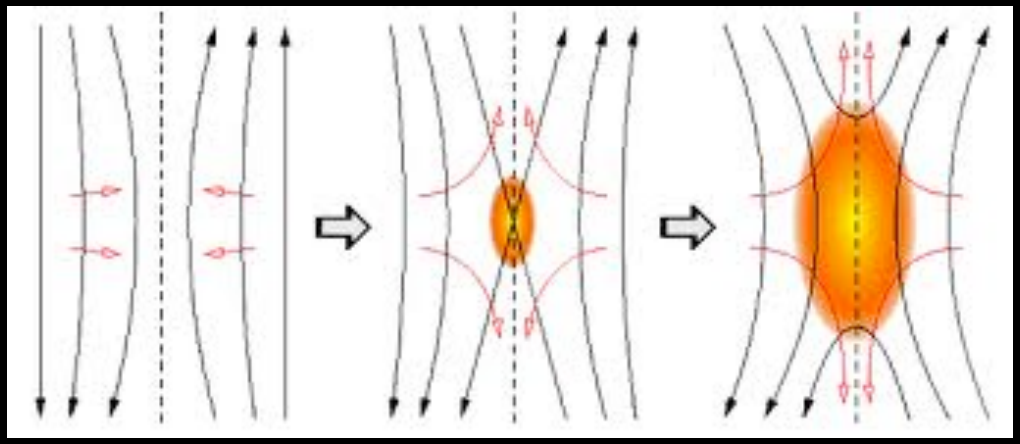
Schmit et al 2013

Lollypops (Cavity substructure)

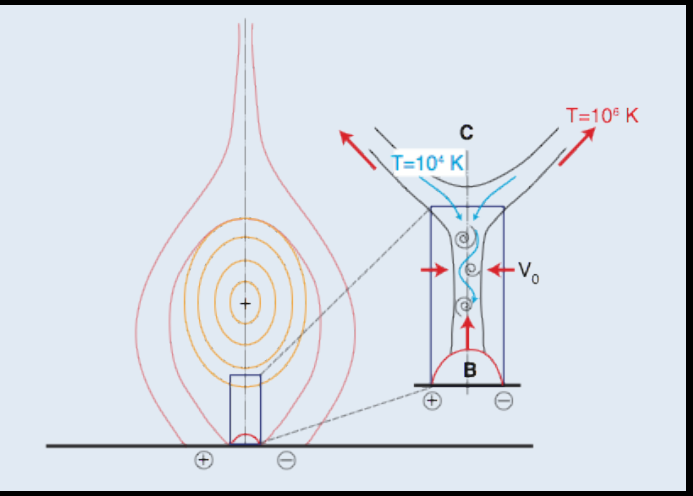


Sharply-defined sub-structure may also arise from magnetic X-line topology --> **reconnection**

Lollypops (Cavity substructure)



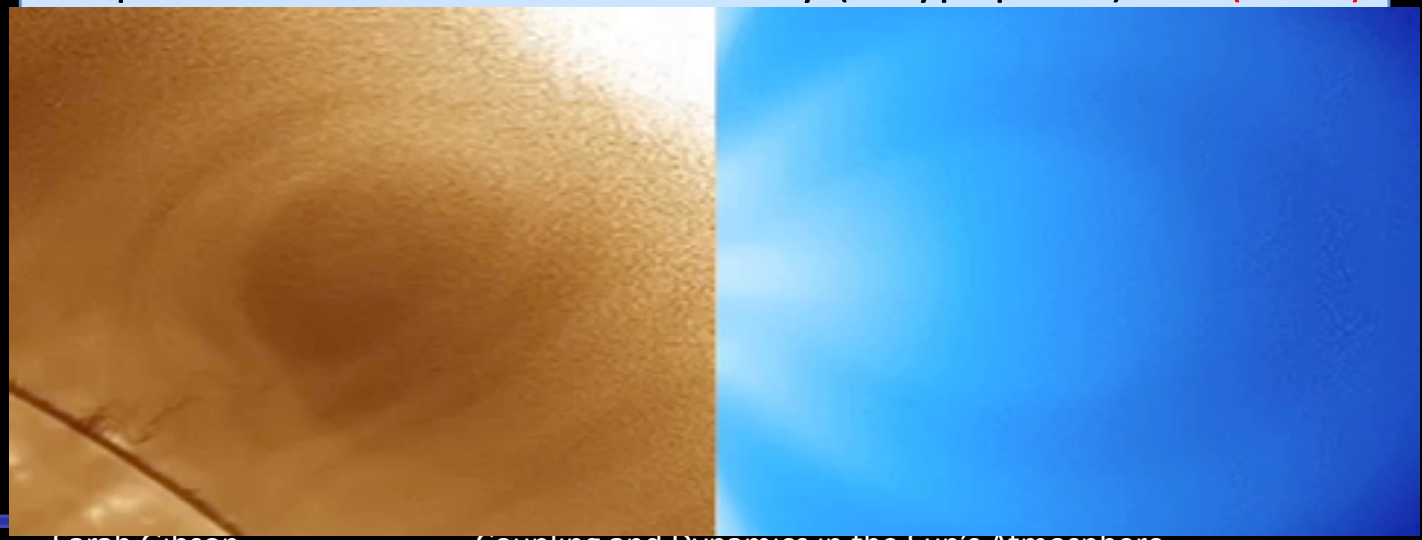
Sharply-defined sub-structure may also arise from magnetic X-line topology --> **reconnection**



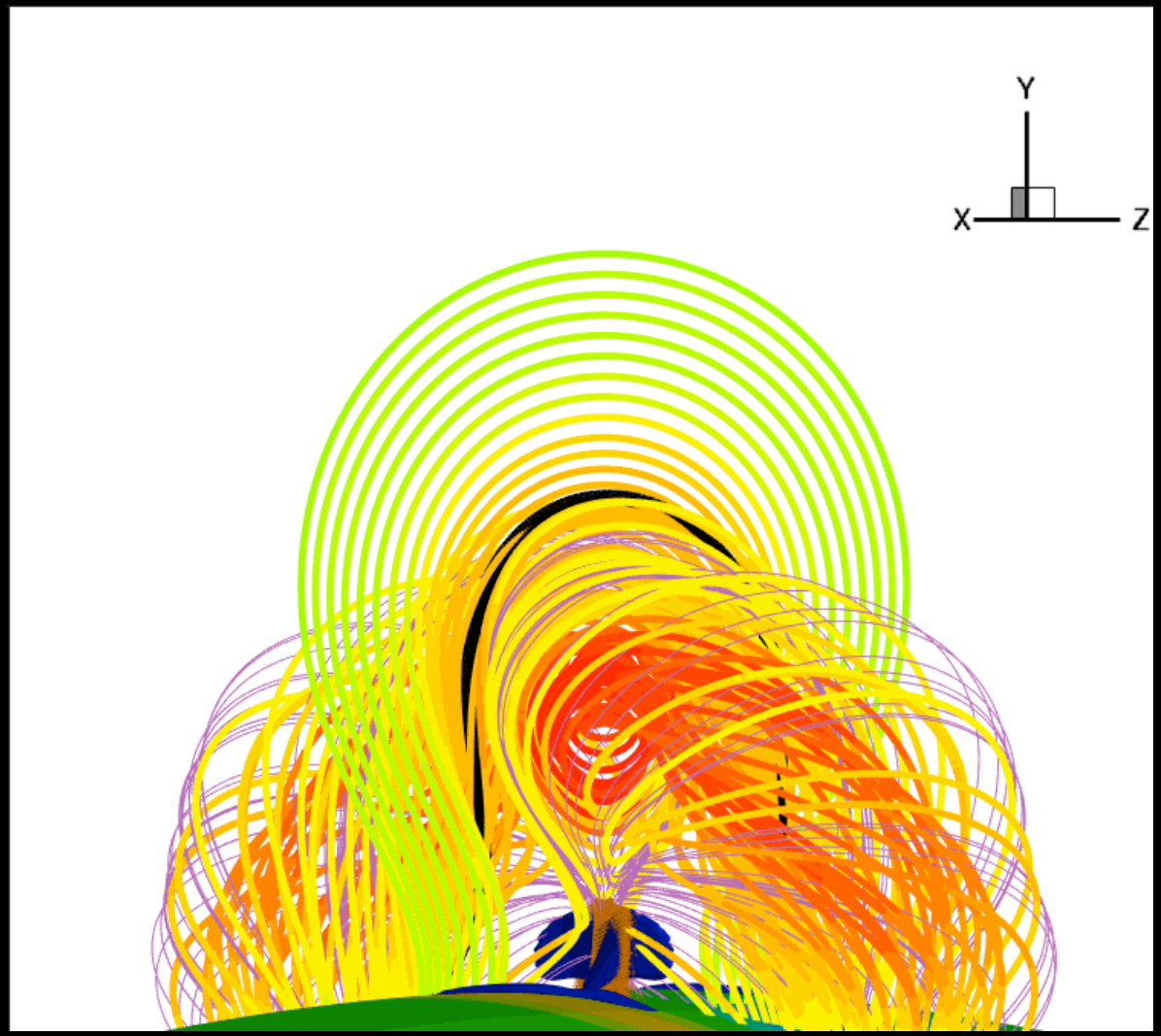
Berger (2012)

Current sheet forms below center of flux rope, with dense horn-like enhancement

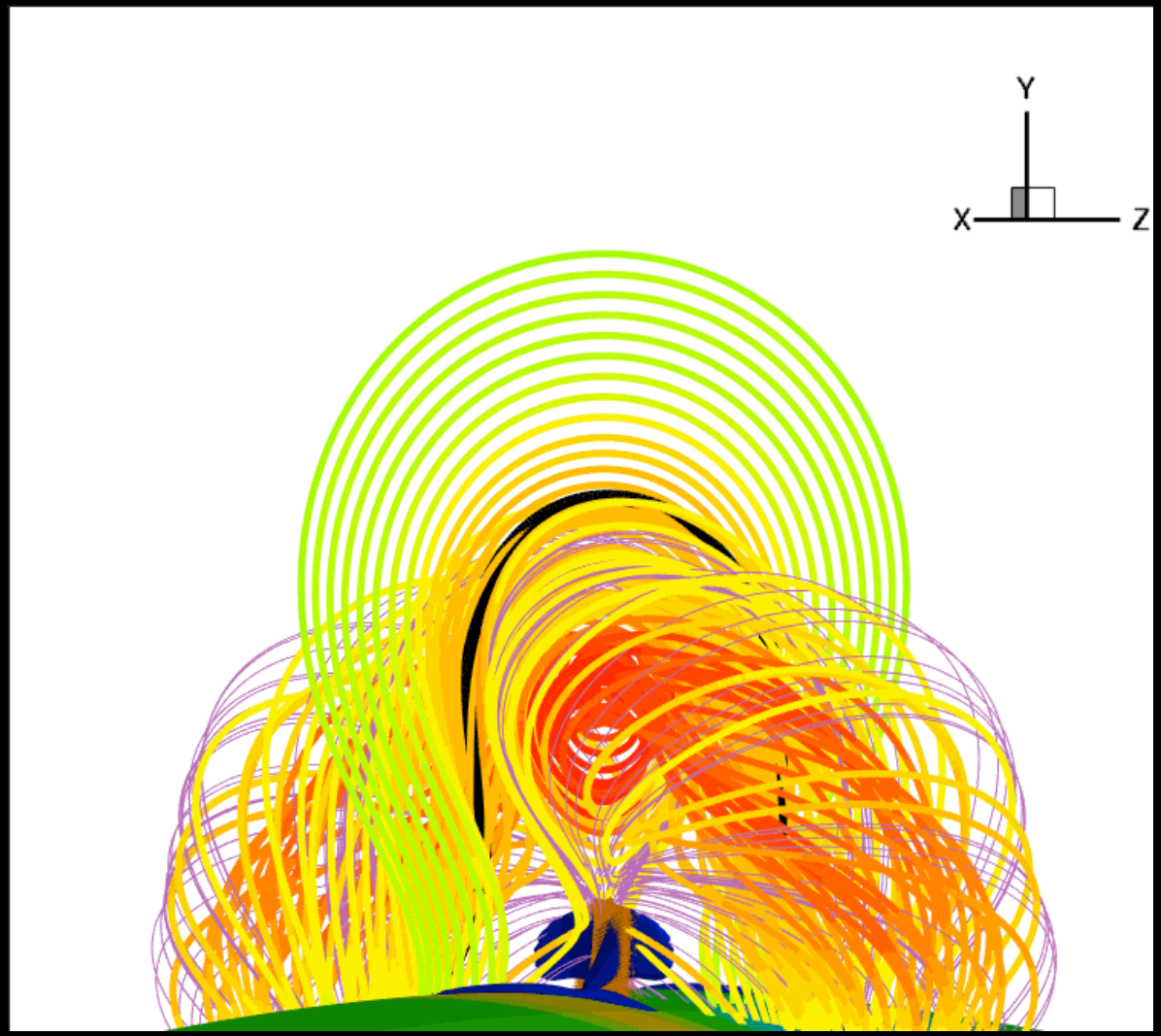
Reconnections lead to flows and low-density/high-temperature center internal to cavity (lollypop-like) Fan (2012)



Lollypops (Cavity substructure)



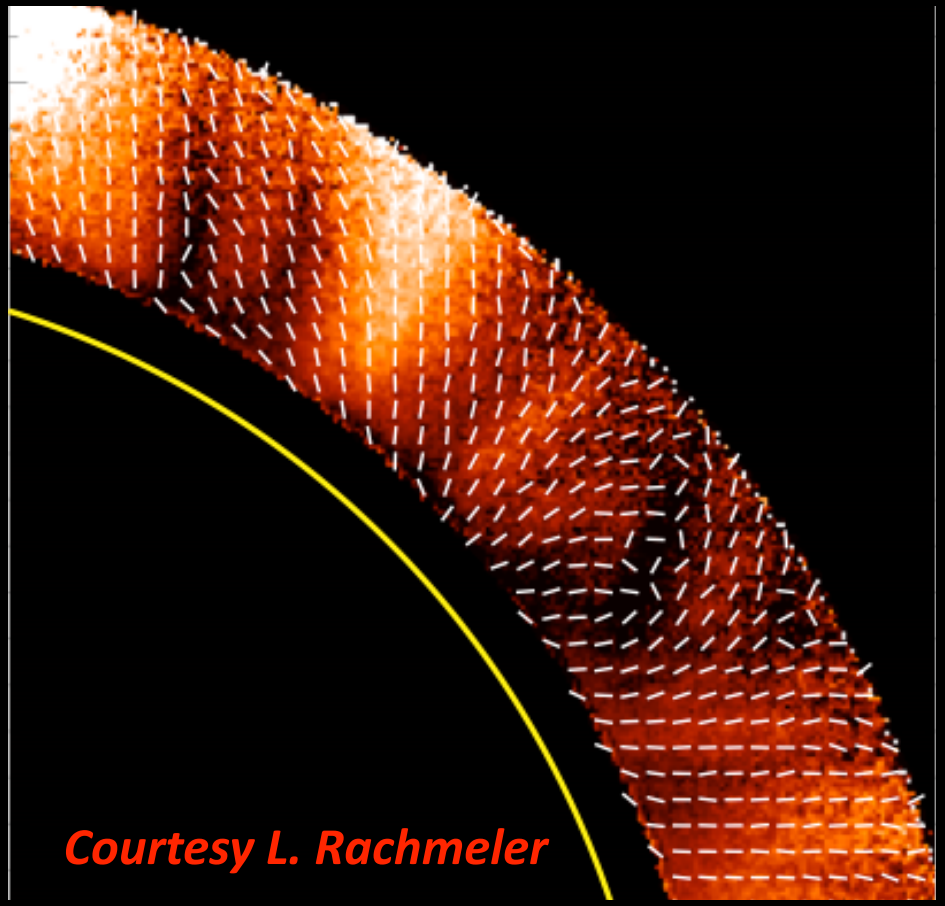
Lollypops (Cavity substructure)



Interpretation: Hot core of reconnected field lines *Fan, 2012*

Lagomorphs (Linear Polarization)

Lagomorphs (Linear Polarization)

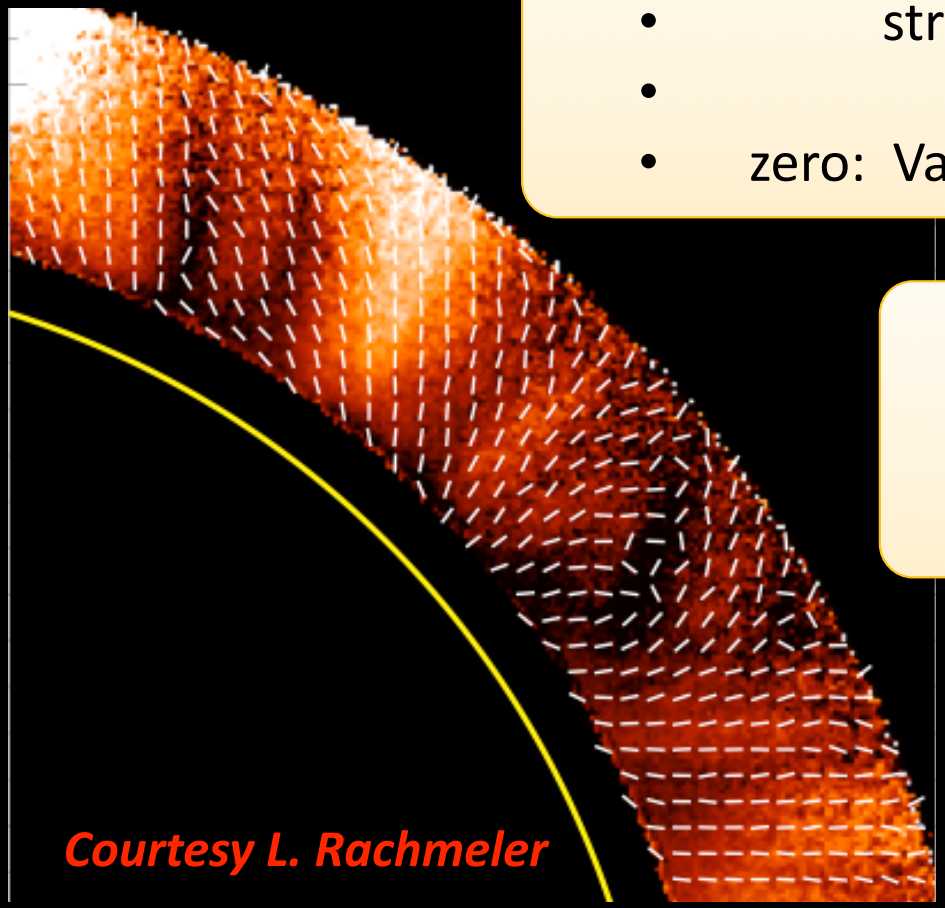


Coronal Multichannel Polarimeter (CoMP): new coronagraph that measures the Stokes vectors and the velocities in optically thin coronal emission lines

Lagomorphs (Linear Polarization)

Primary observable: fraction of linearly-polarized light (L/I)

- strong signal: **B** in plane-of-sky (POS)
- zero: **B** along line-of-sight (LOS)
- zero: Van Vleck angle between **B** and radial ~54

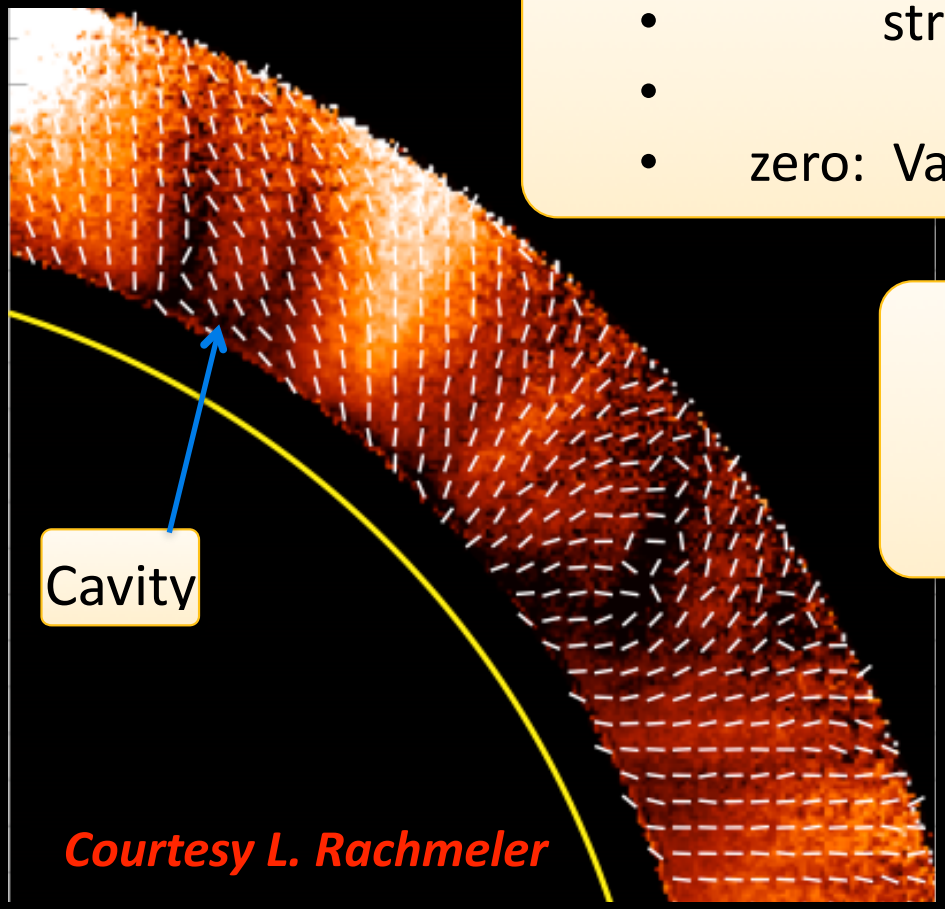


L/I direction = POS component of B (integrated along LOS!)

- flips by 90 degrees at Van Vleck angle

Coronal Multichannel Polarimeter (CoMP): new coronagraph that measures the Stokes vectors and the velocities in optically thin coronal emission lines

Lagomorphs (Linear Polarization)



Primary observable: fraction of linearly-polarized light (L/I)

- strong signal: **B** in plane-of-sky (POS)
- zero: **B** along line-of-sight (LOS)
- zero: Van Vleck angle between **B** and radial ~54

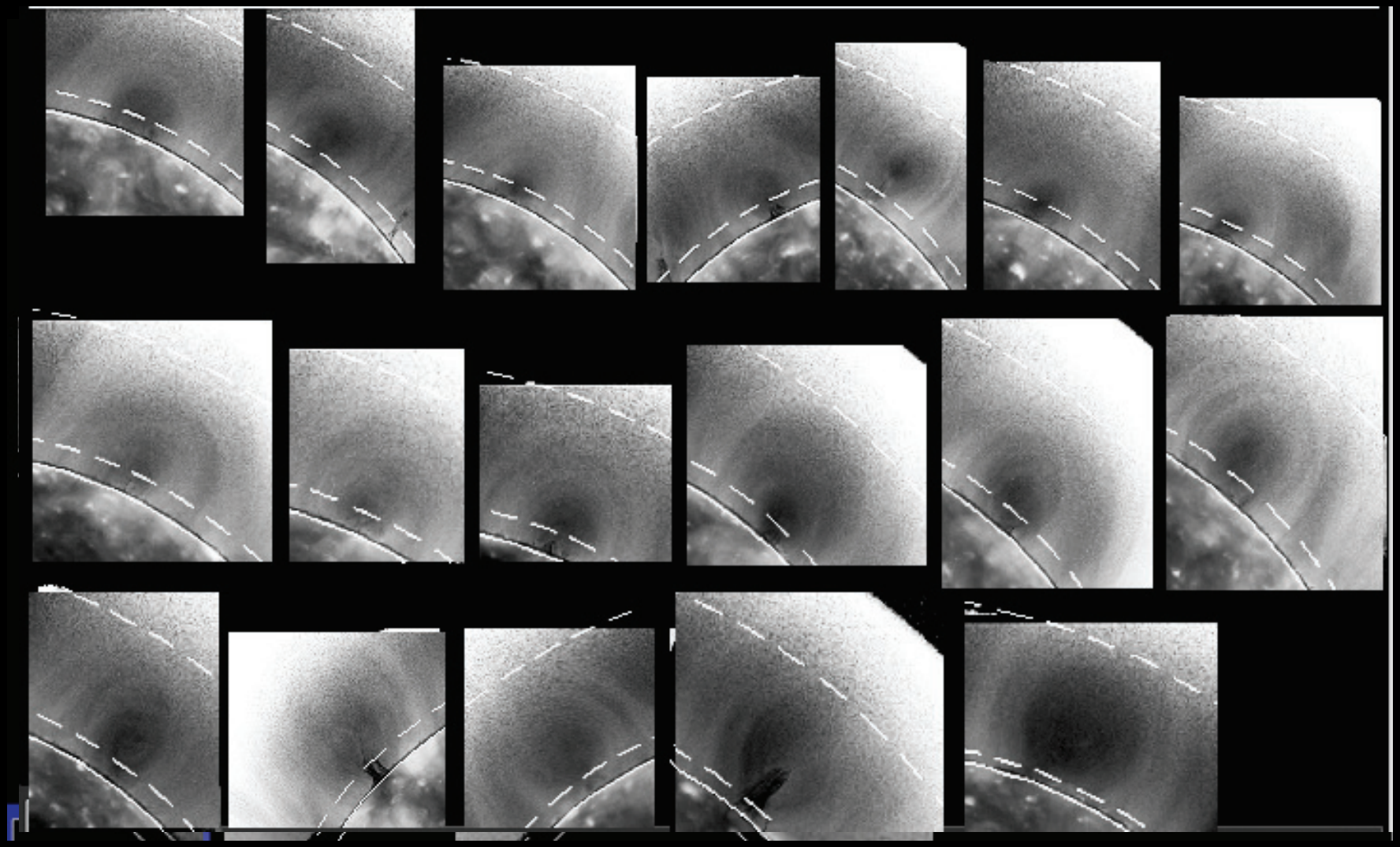
L/I direction = POS component of B (integrated along LOS!)

- flips by 90 degrees at Van Vleck angle

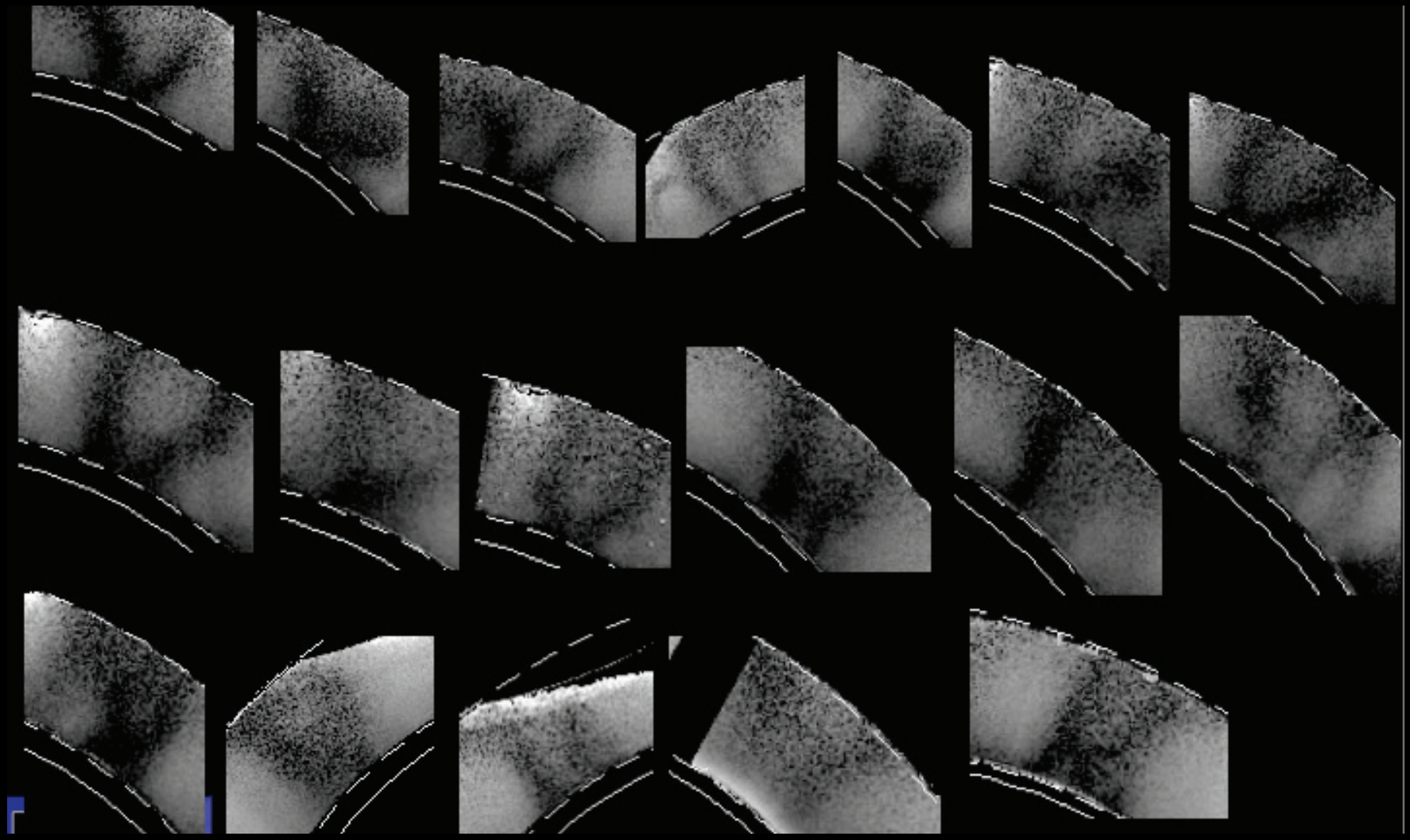
Sensitive to presence of coronal currents (Judge et al., 2006)

Coronal Multichannel Polarimeter (CoMP): new coronagraph that measures the Stokes vectors and the velocities in optically thin coronal emission lines

Lagomorphs (Linear Polarization)



Lagomorphs (Linear Polarization)

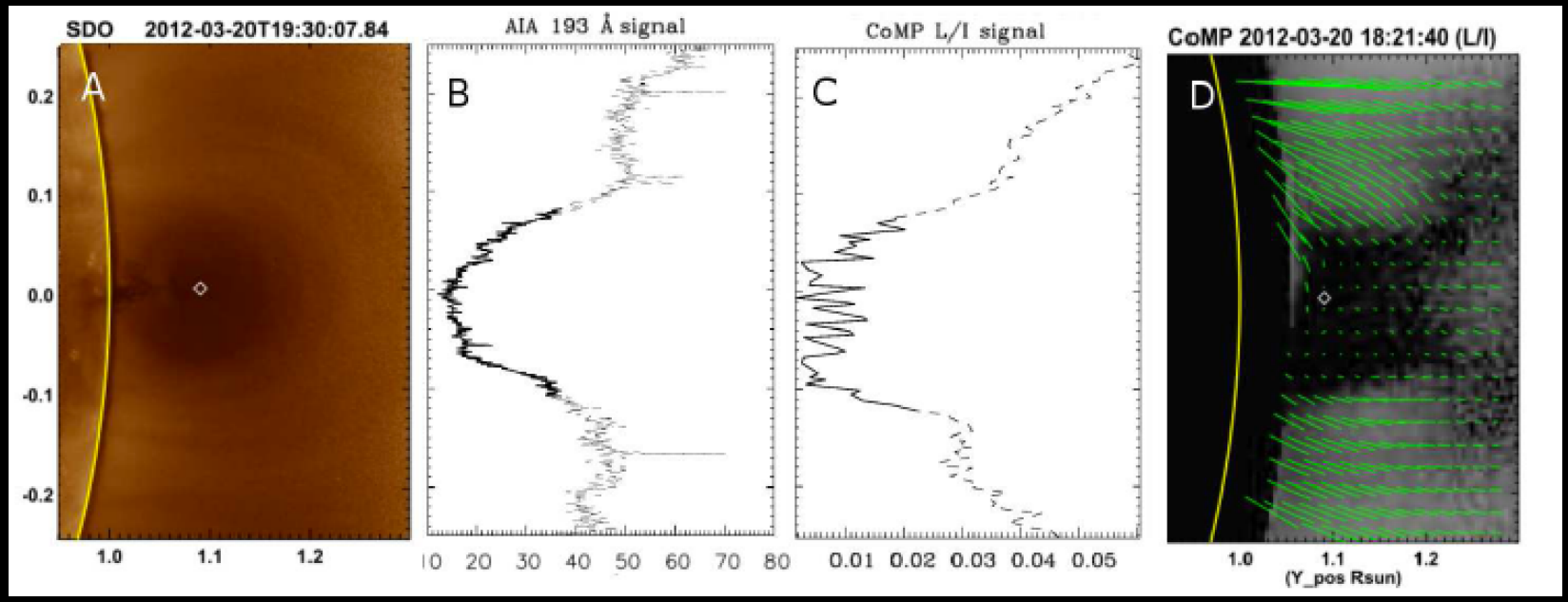


Lagomorphs (Linear Polarization)

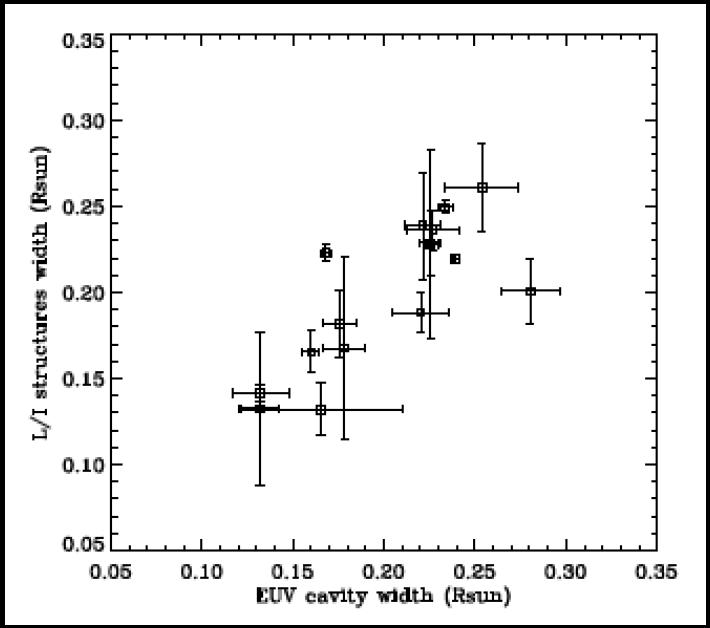
Lagomorphs (Linear Polarization)

Bak-Steslicka et al, 2014

Lagomorph "head" collocated with cavity



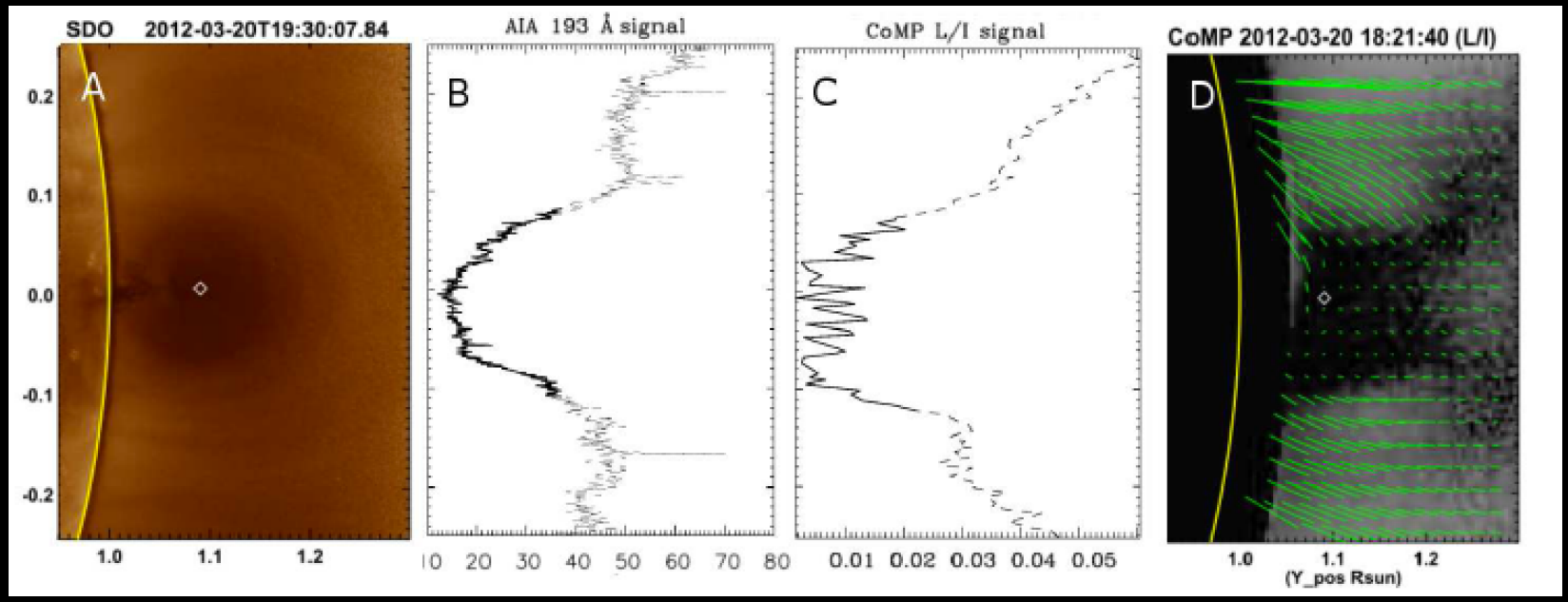
Lagomorphs (Linear Polarization)



Lagomorph and cavity sizes correlate

Bak-Steslicka et al, 2014

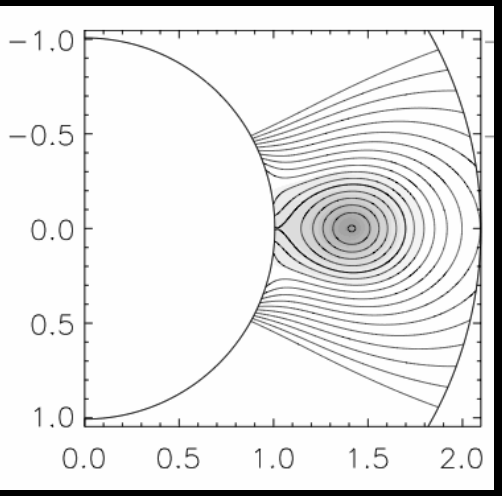
Lagomorph "head" collocated with cavity



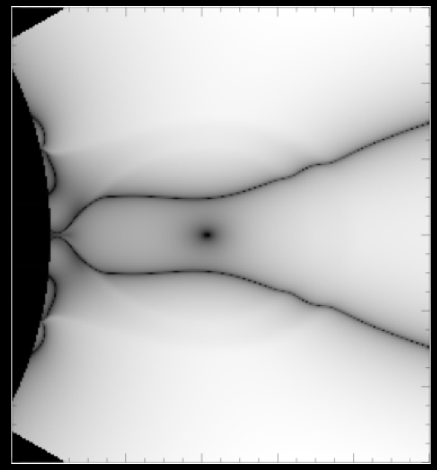
Lagomorphs (Linear Polarization)

Interpretation: flux rope

Model B (POS)



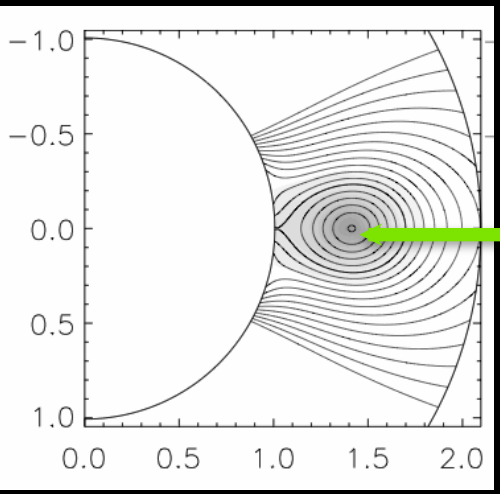
Model L/I (POS)



Lagomorphs (Linear Polarization)

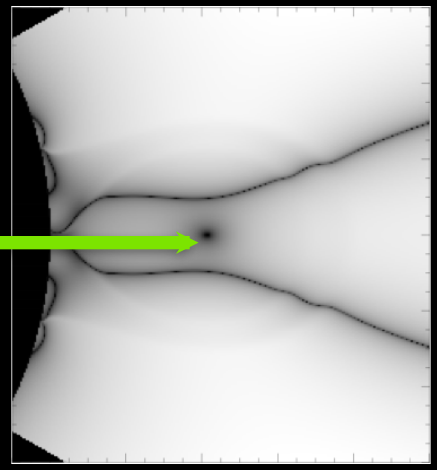
Interpretation: flux rope

Model B (POS)



Flux rope axis

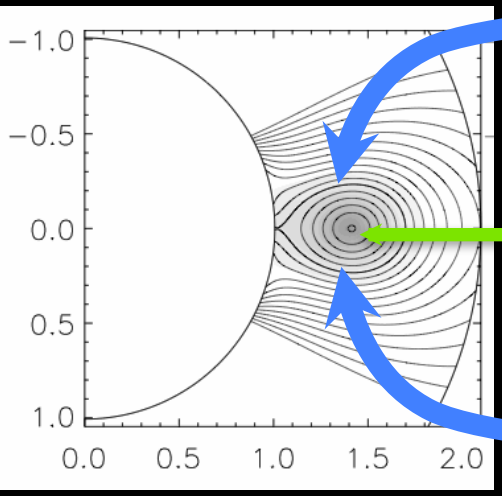
Model L/I (POS)



Lagomorphs (Linear Polarization)

Interpretation: flux rope

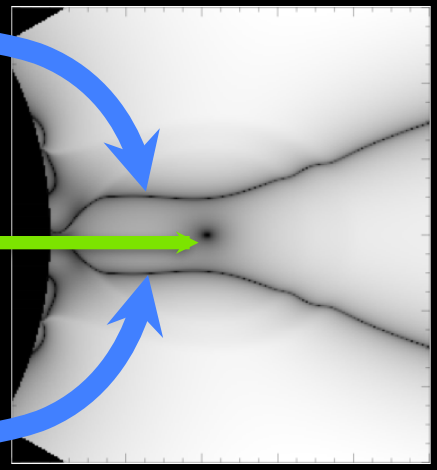
Model B (POS)



Van Vleck inversion in flux rope

Flux rope axis

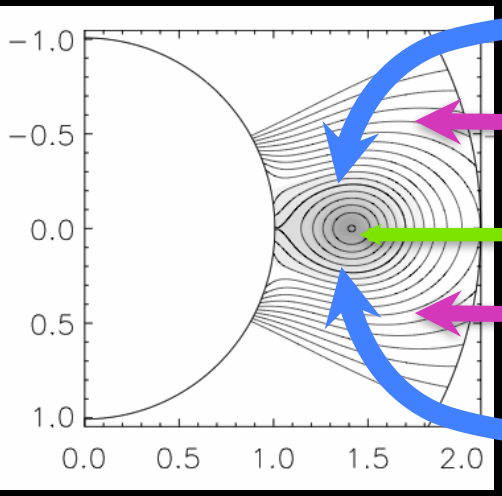
Model L/I (POS)



Lagomorphs (Linear Polarization)

Interpretation: flux rope

Model B (POS)

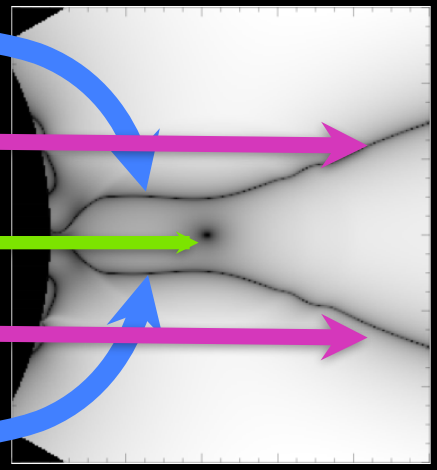


Van Vleck inversion in flux rope

Van Vleck inversion in arcade

Flux rope axis

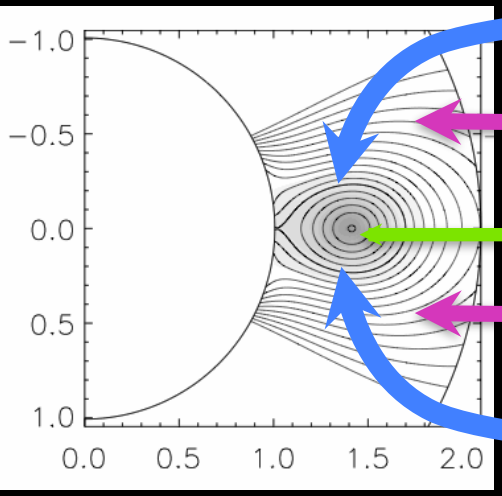
Model L/I (POS)



Lagomorphs (Linear Polarization)

Interpretation: flux rope

Model B (POS)

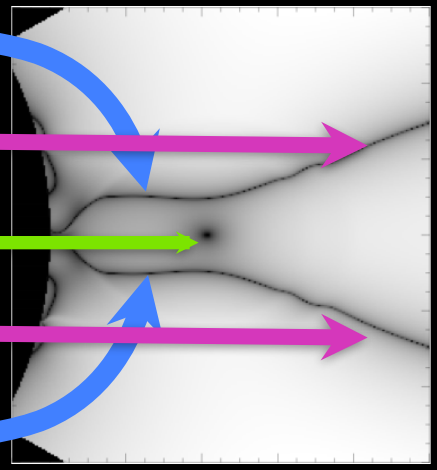


Van Vleck inversion in flux rope

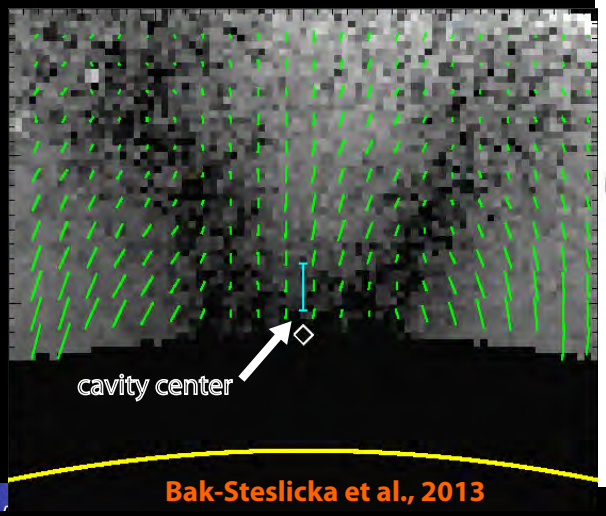
Van Vleck inversion in arcade

Flux rope axis

Model L/I (POS)

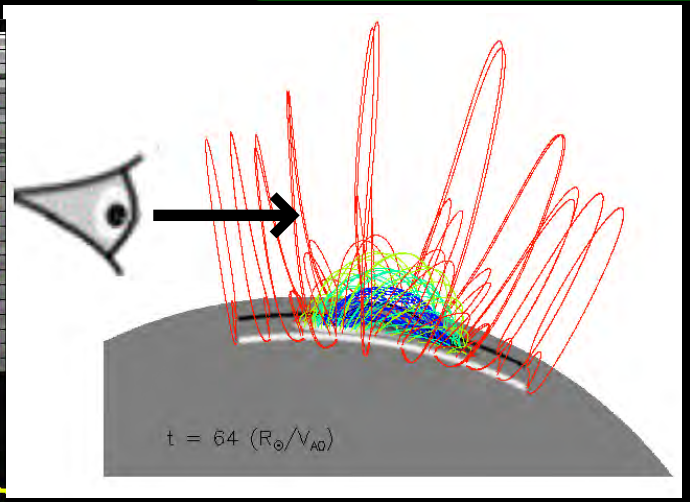


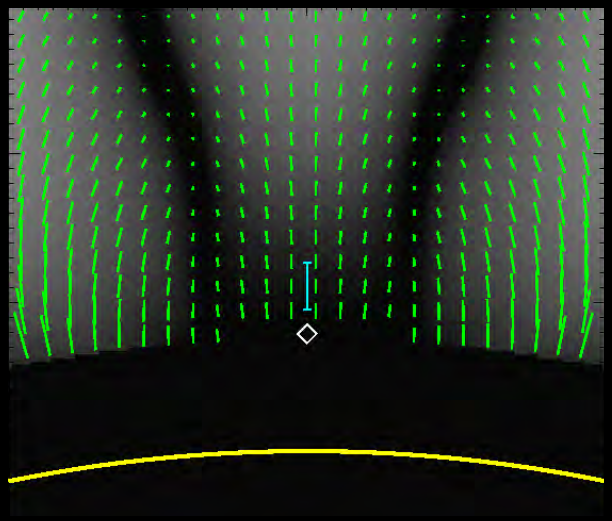
Linear polarization lagomorph in coronal cavity



Bak-Steslicka et al., 2013

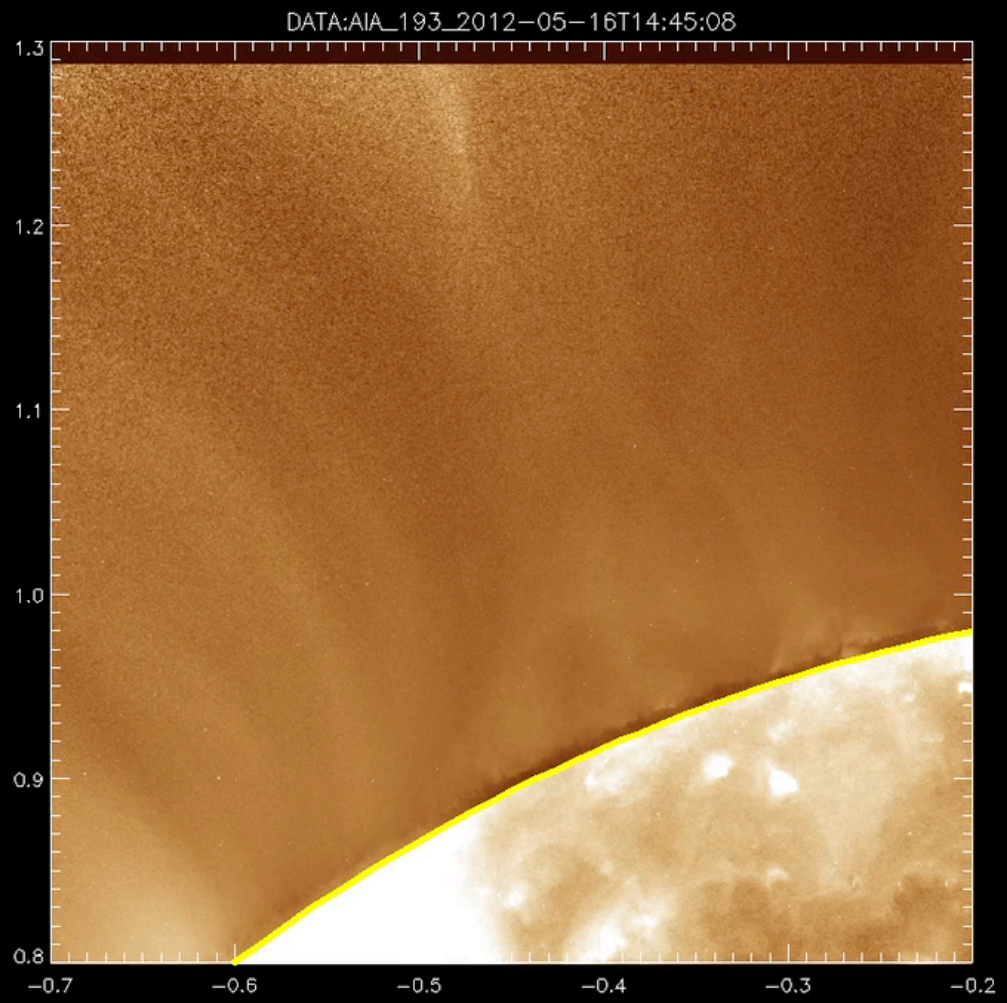
Flux rope model forward-integrated for linear polarization





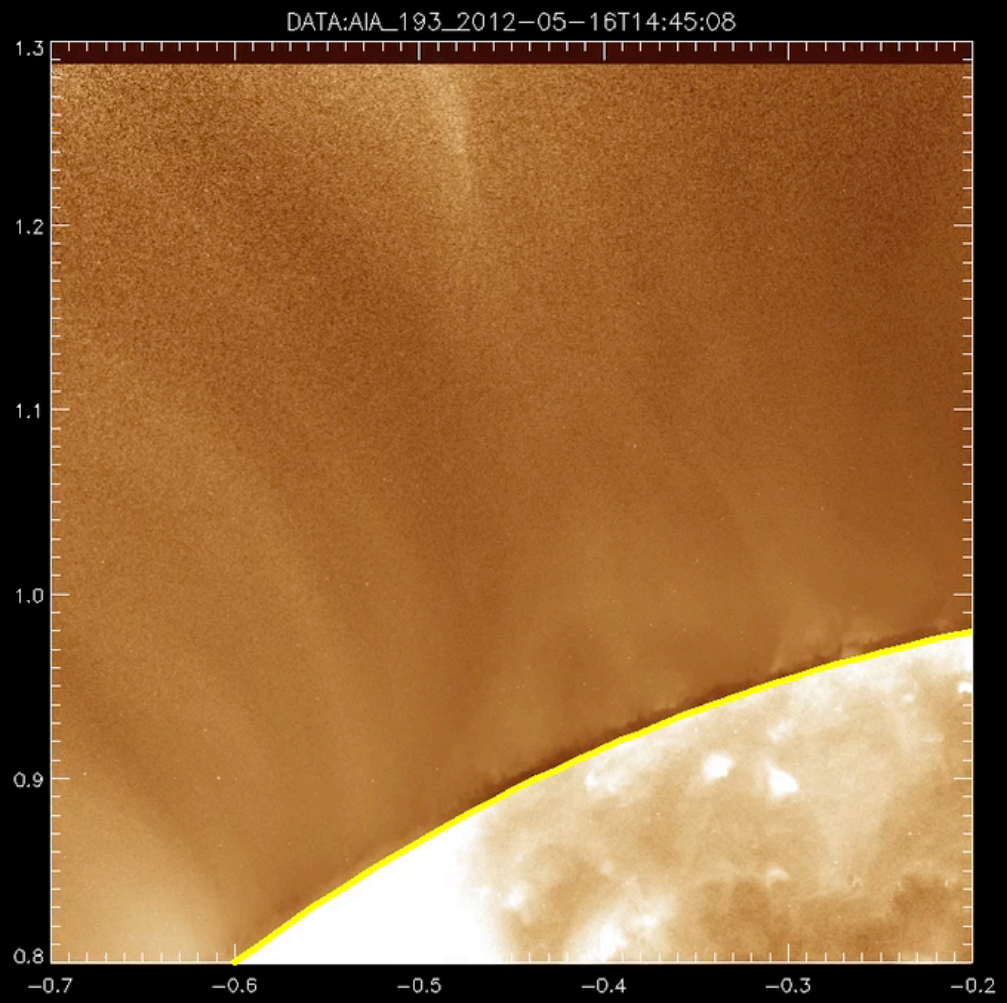
Liftoff! (Cavity clues to CMEs)

Cavities “bodily” erupt as CMEs



Liftoff! (Cavity clues to CMEs)

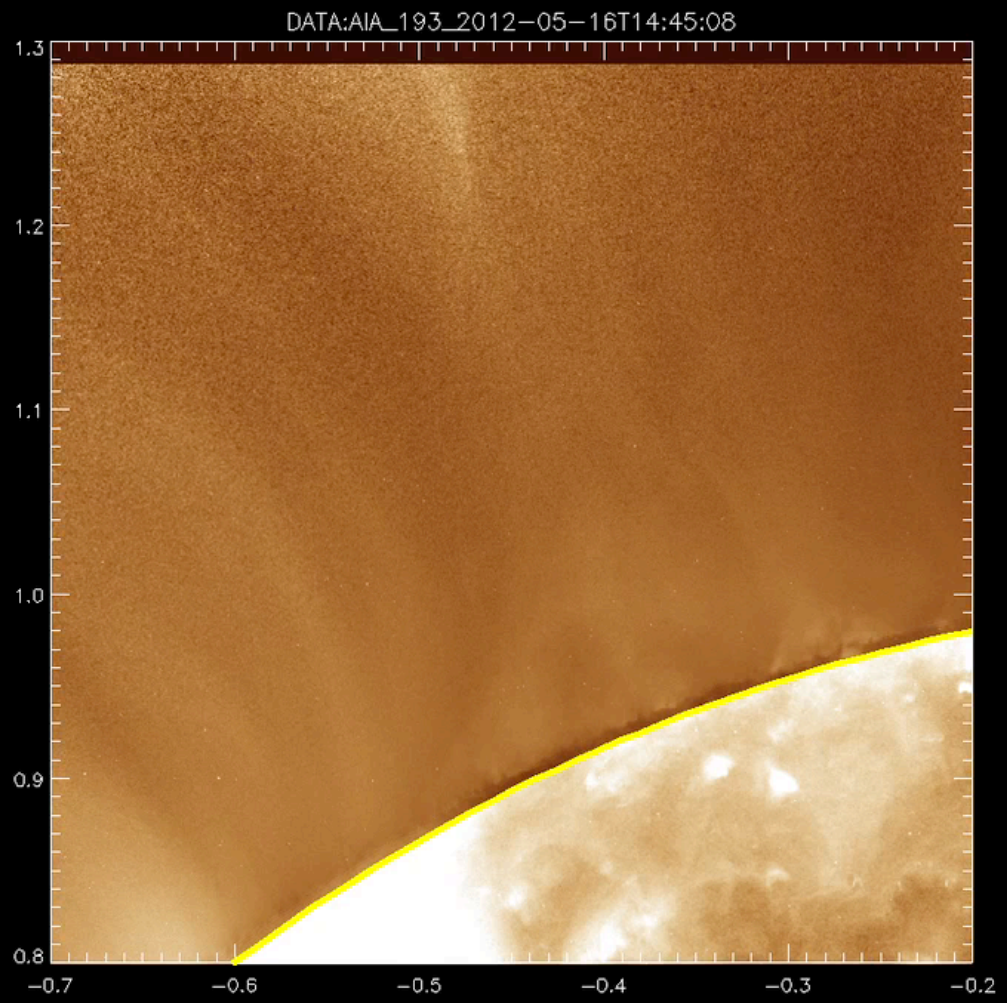
Cavities “bodily” erupt as CMEs



Liftoff! (Cavity clues to CMEs)

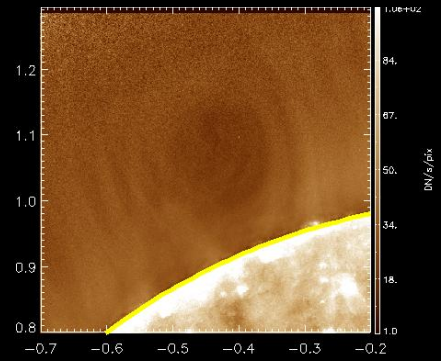
Cavities “bodily” erupt as CMEs

Note the **shape** (tear-drop)

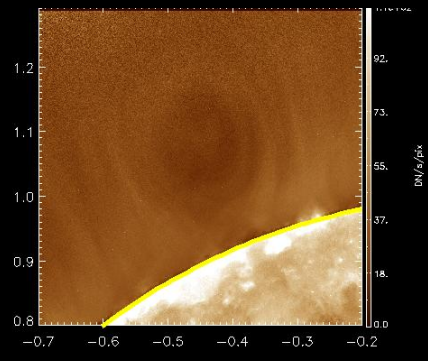


Liftoff! (Cavity clues to CMEs)

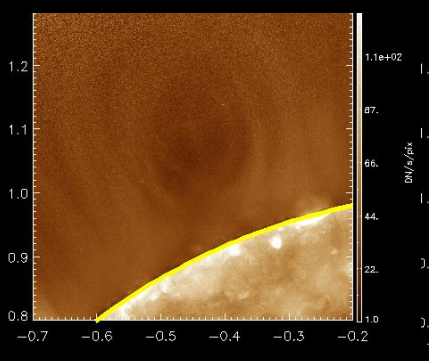
2012-05-14 06:00



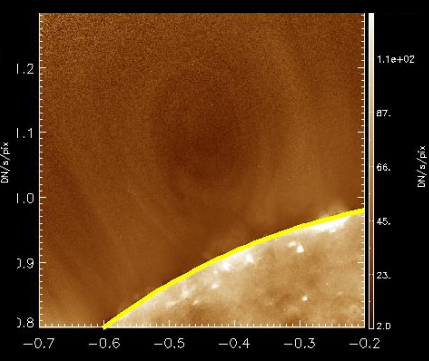
2012-05-14 12:00



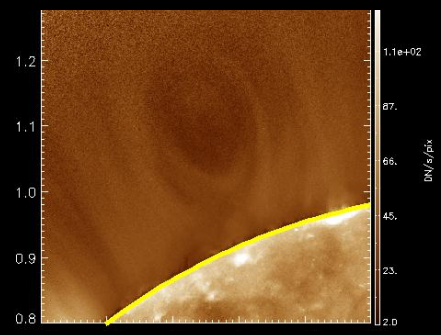
2012-05-14 18:00



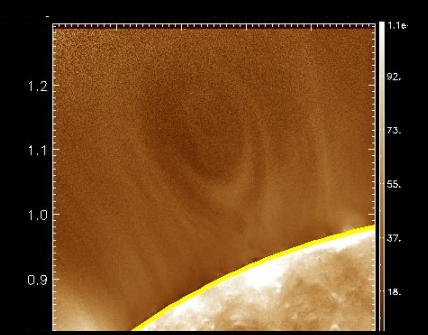
2012-05-15 00:00



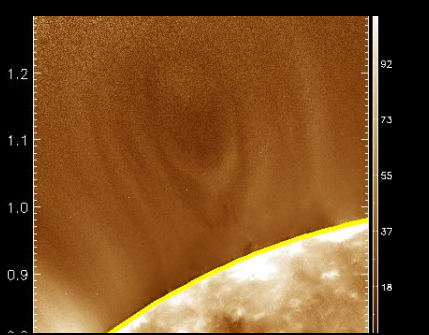
2012-05-15 06:00



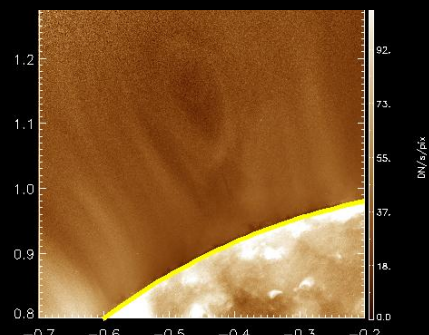
2012-05-15 12:00



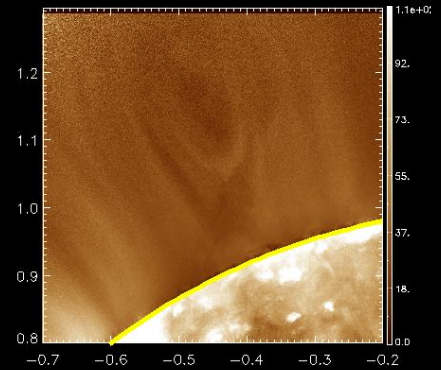
2012-05-15 18:00



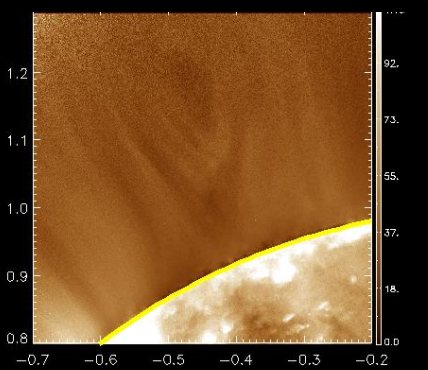
2012-05-16 00:00



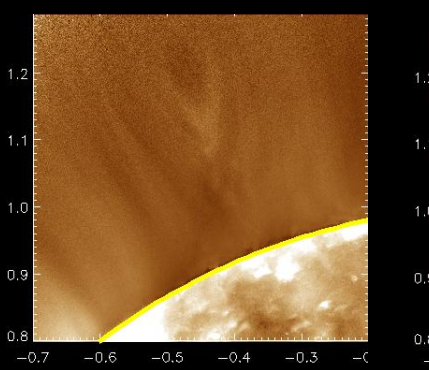
2012-05-16 02:00



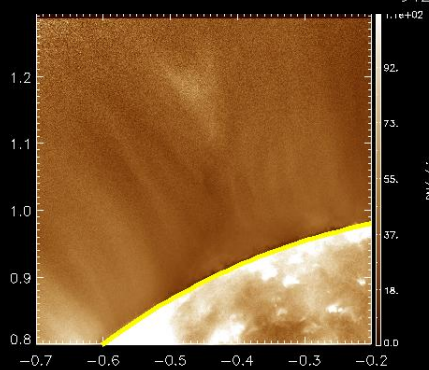
2012-05-16 04:00



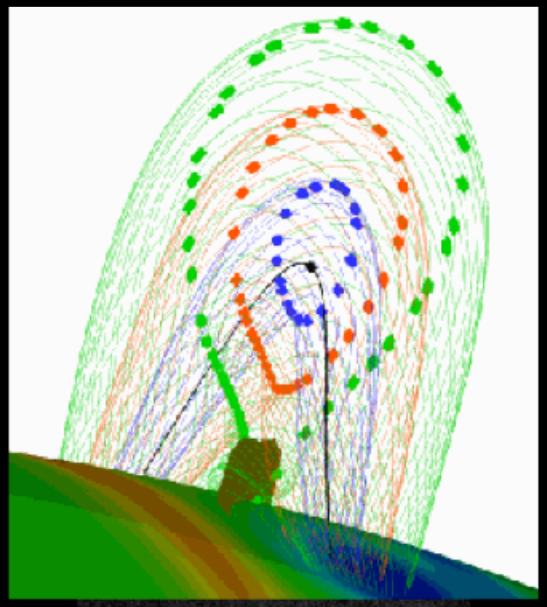
2012-05-16 06:00



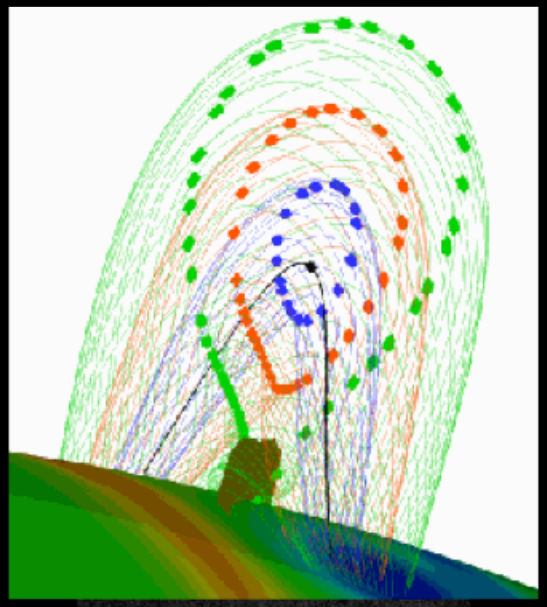
2012-05-16 08:00



Liftoff! (Cavity clues to CMEs)

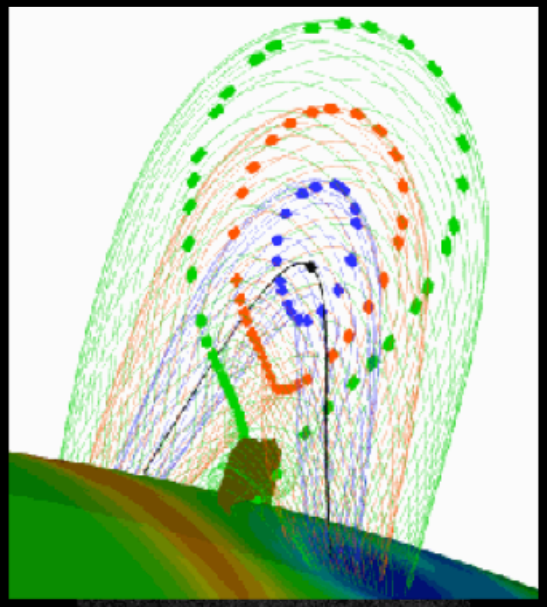


Liftoff! (Cavity clues to CMEs)

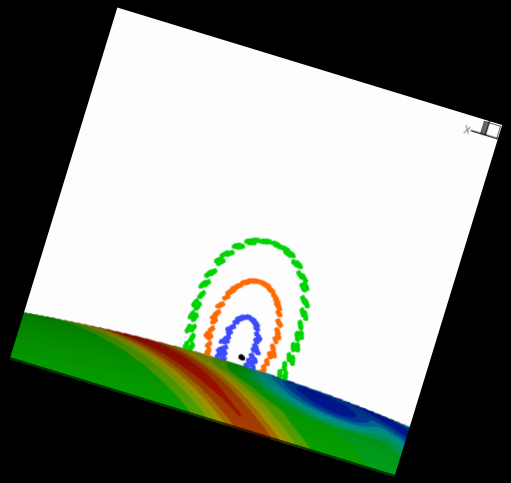


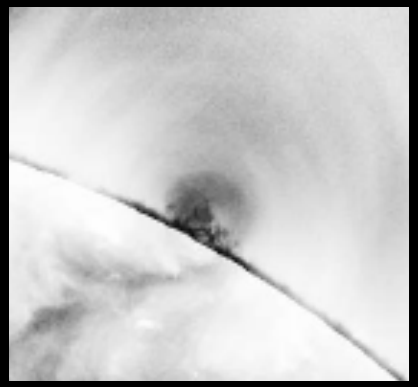
Shape predicts eruption

Liftoff! (Cavity clues to CMEs)



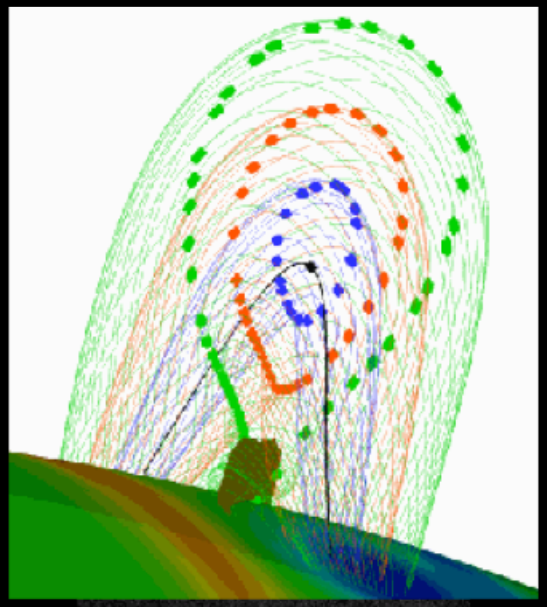
Shape predicts eruption

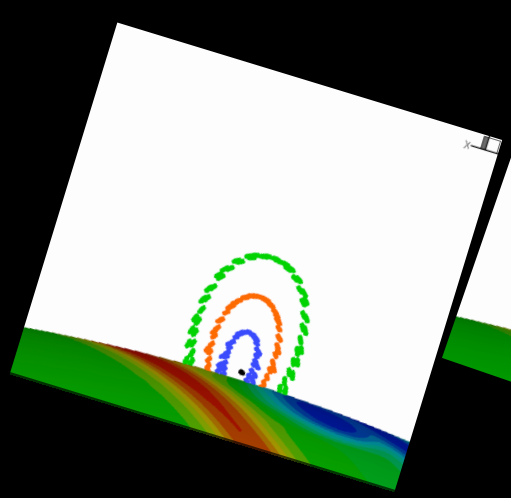


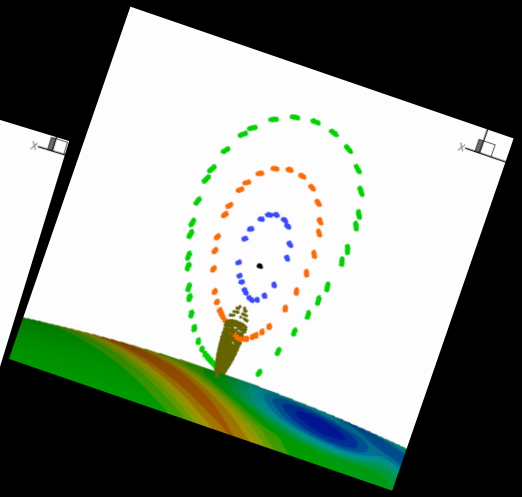


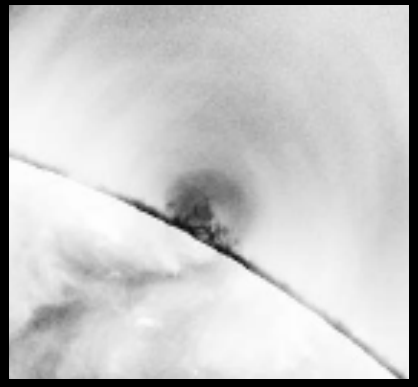
Liftoff! (Cavity clues to CMEs)

Shape predicts eruption



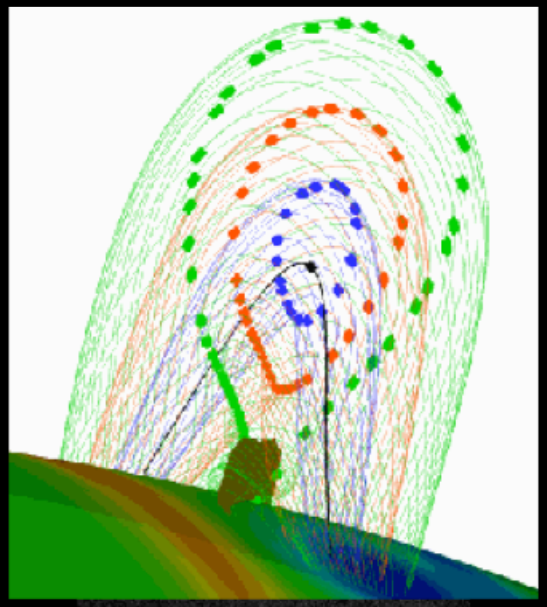


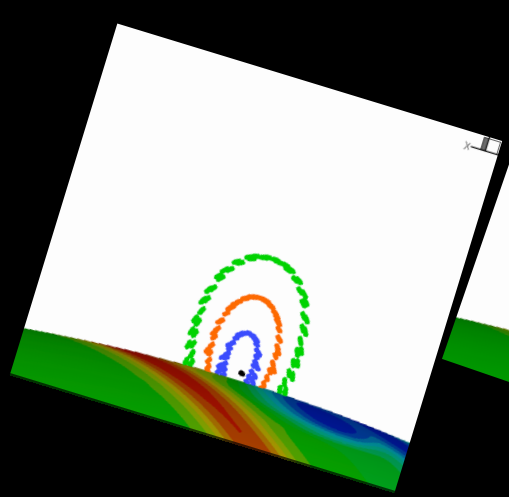


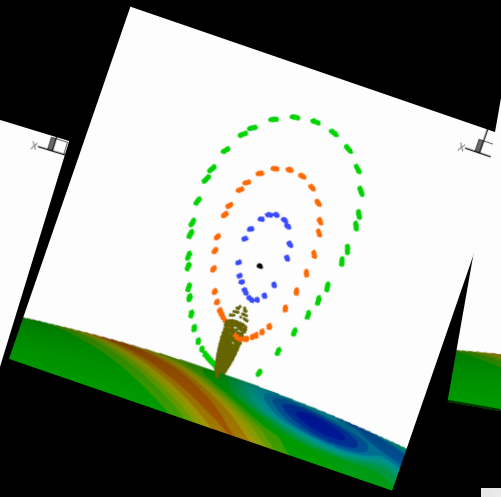


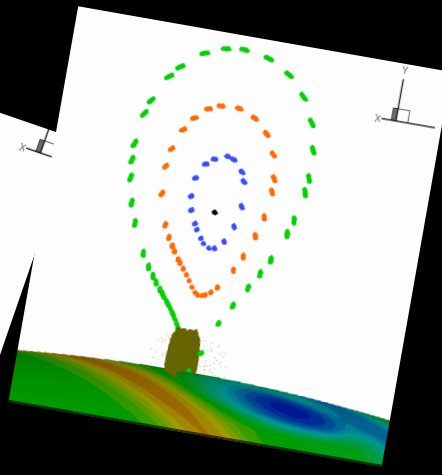
Liftoff! (Cavity clues to CMEs)

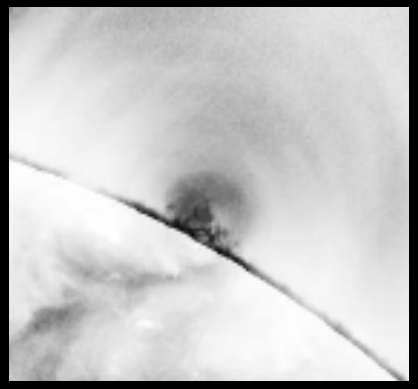
Shape predicts eruption



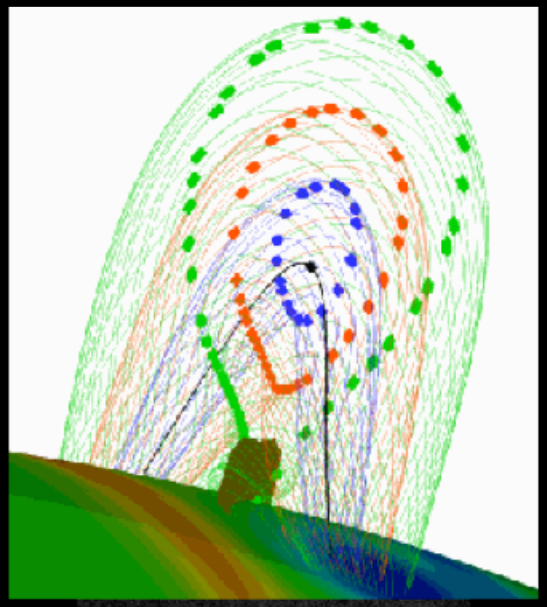








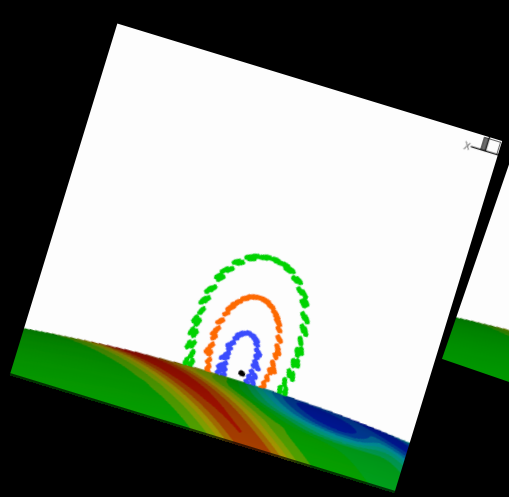
Liftoff! (Cavity clues to CMEs)

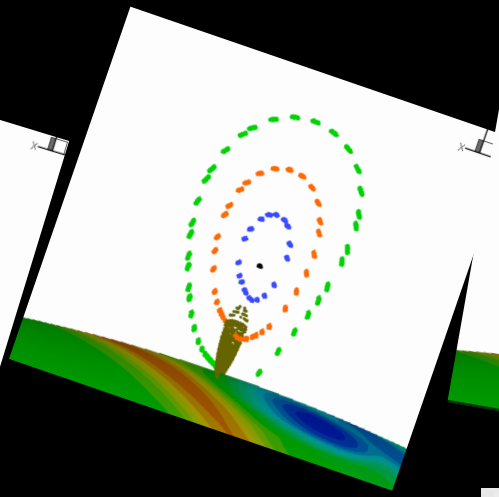


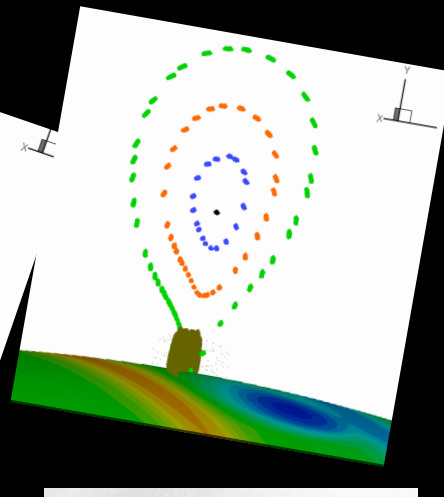
Shape predicts eruption

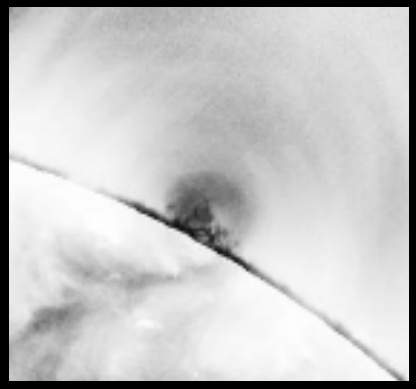
10% semicircular erupted
23% elliptical erupted
68% of tear-shaped erupted

Forland et al. 2013

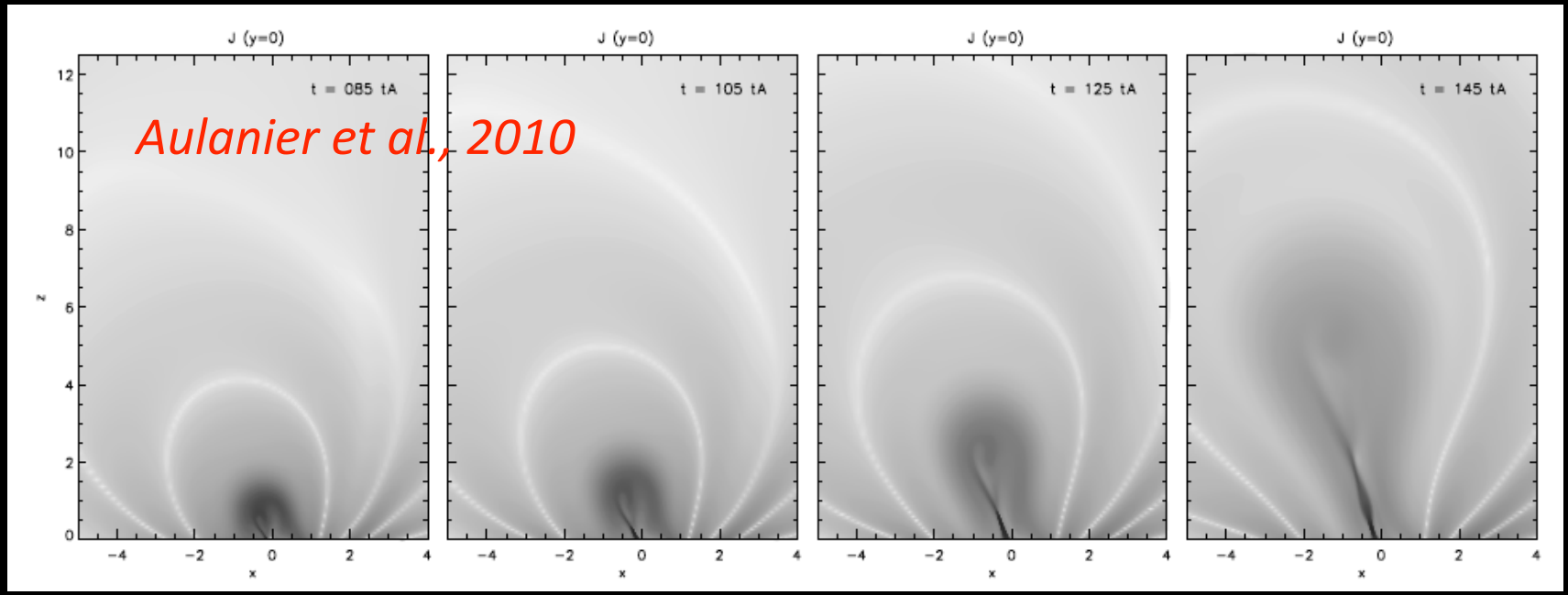








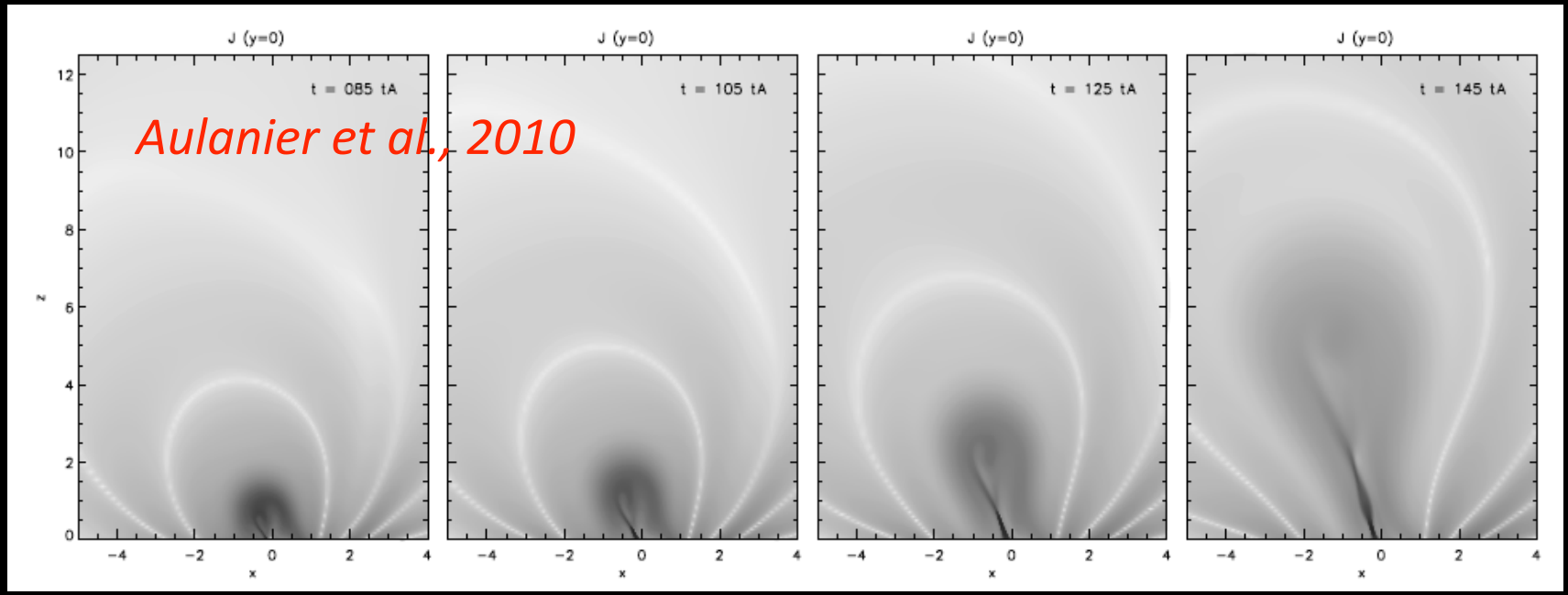
Liftoff! (Cavity clues to CMEs)



Aulanier et al., 2010

Also, Savcheva et al, 2012; Fan, 2012

Liftoff! (Cavity clues to CMEs)



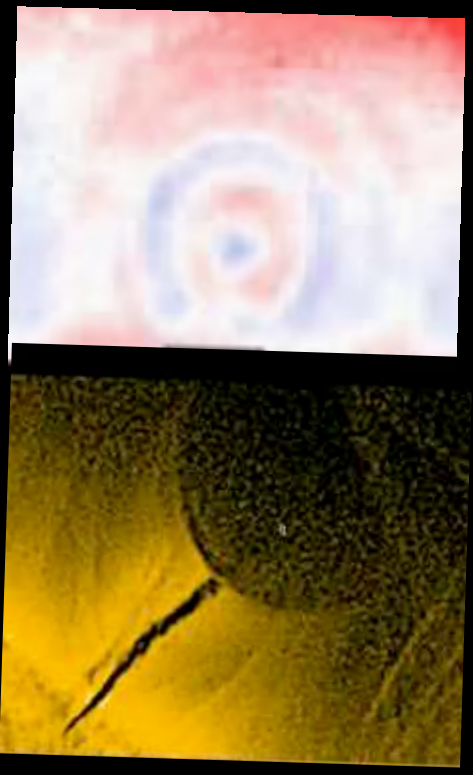
Aulanier et al., 2010

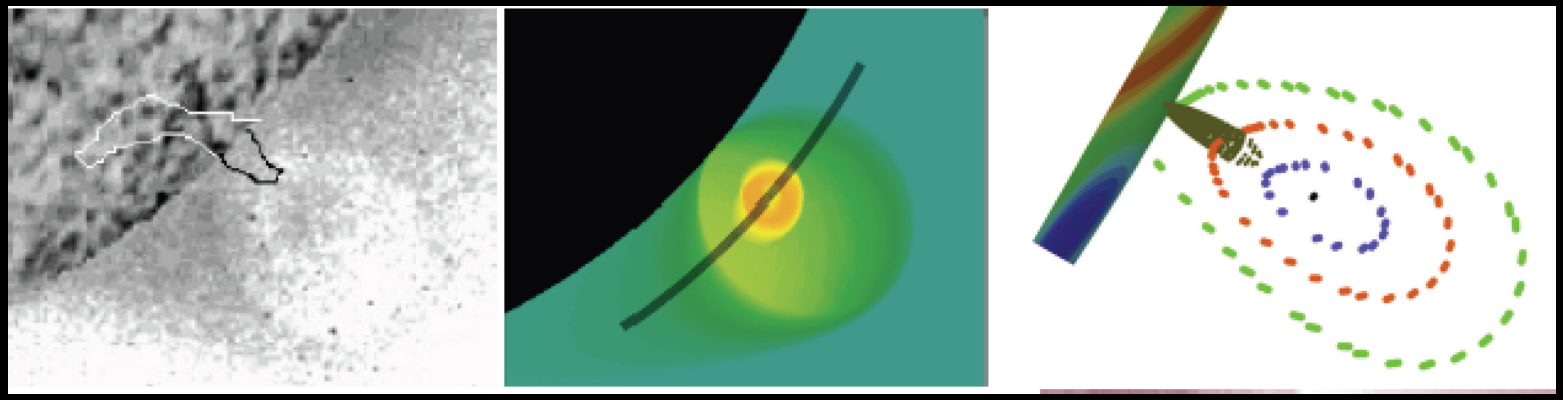
Also, Savcheva et al, 2012; Fan, 2012

Interpretation:

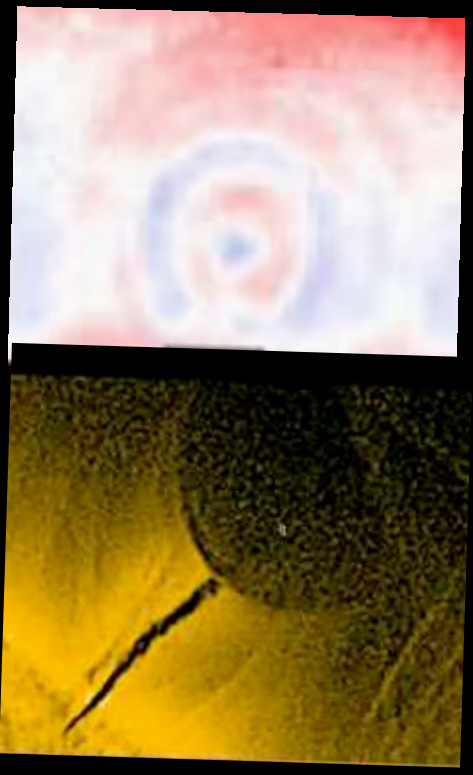
- **Current sheet forms below flux rope —> tether-cutting reconnections (hot core, central void)**
- **Drives slow rise of flux rope (tear-drop shape forms)**
- **Reaches height for torus instability —> CME**

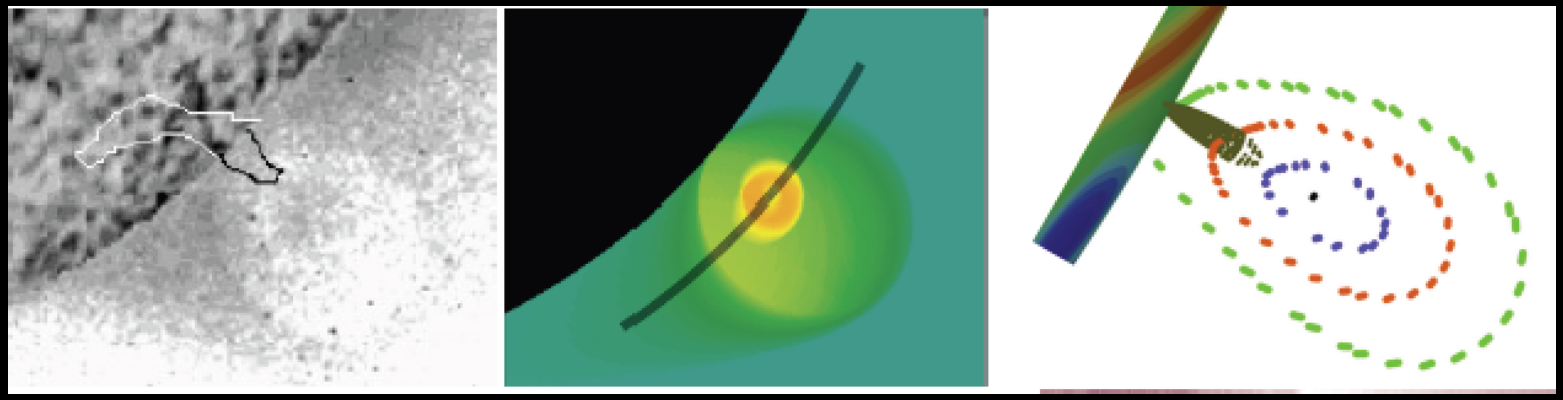
Conclusions: Lollypops





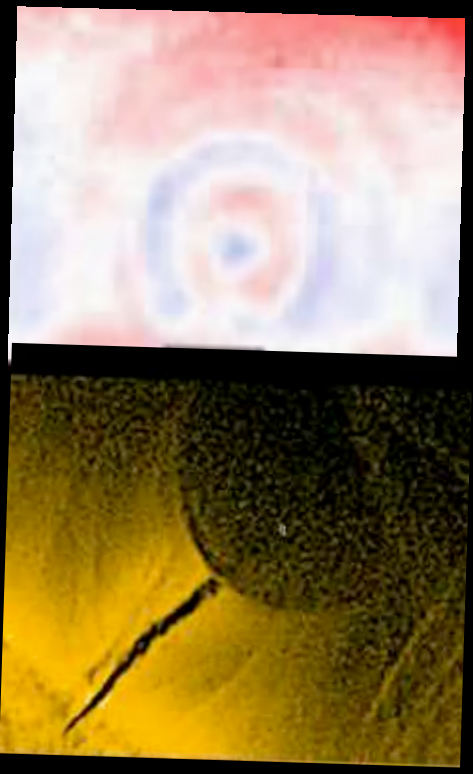
Conclusions: Lollypops

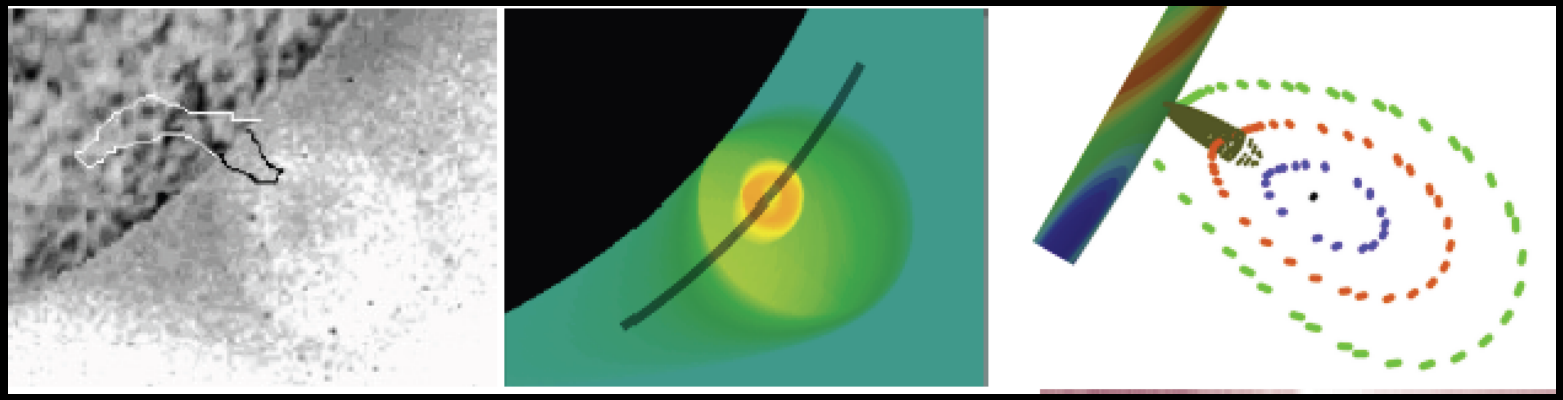




Thermodynamic and/or topological interfaces associated with nested toroidal flux surfaces

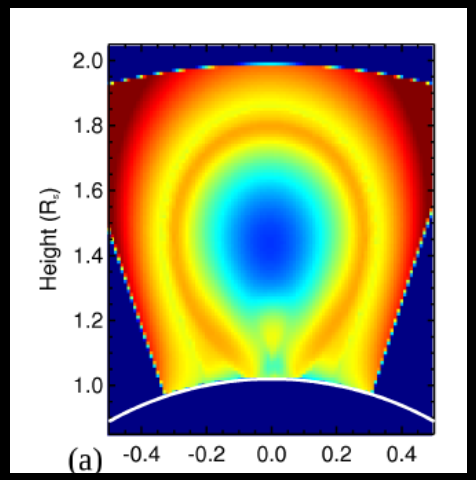
Conclusions: Lollypops

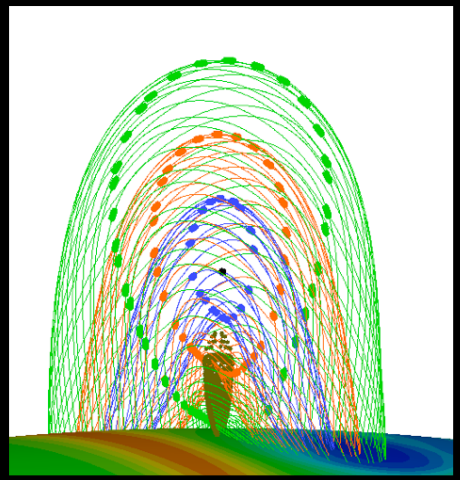




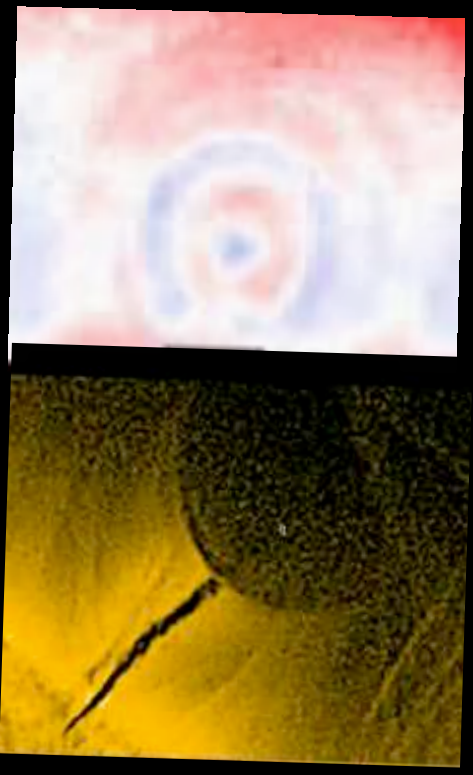
Thermodynamic and/or topological interfaces associated with nested toroidal flux surfaces

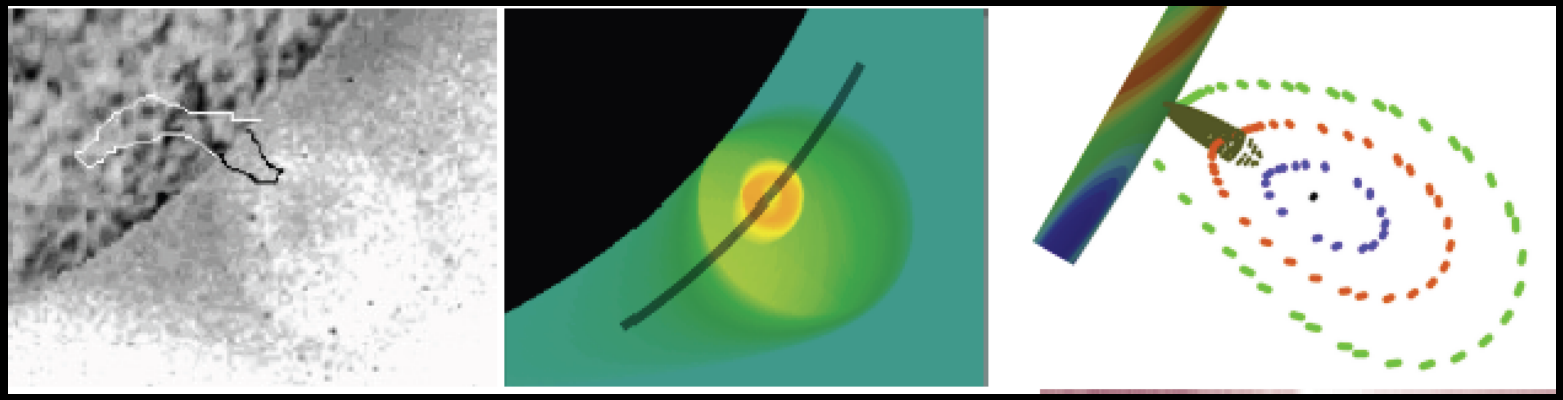
Field line length/geometry



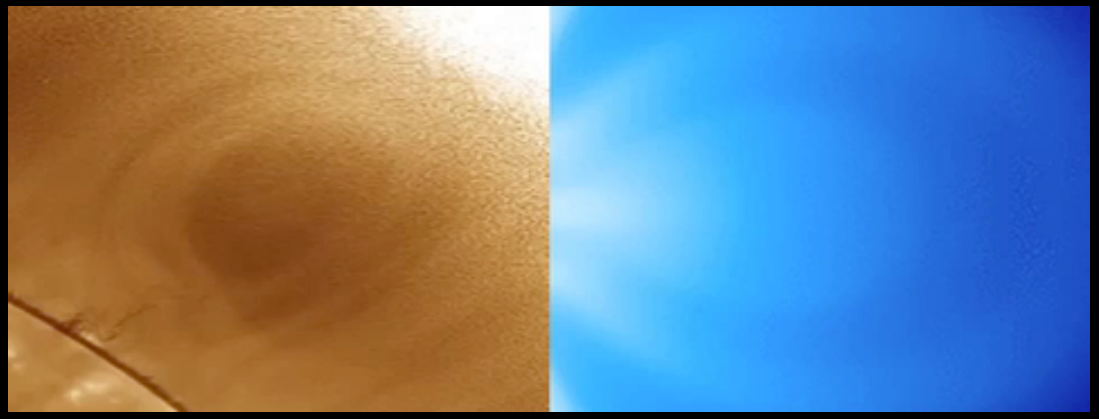


Conclusions: Lollypops



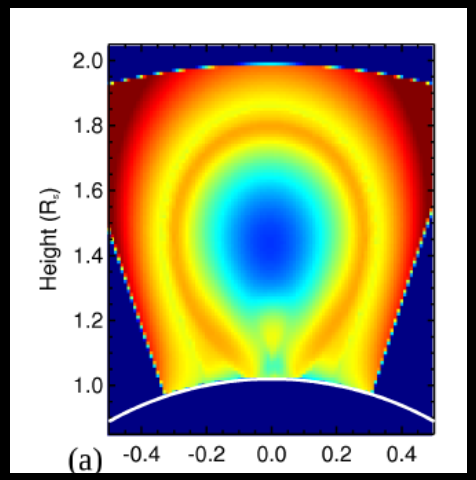


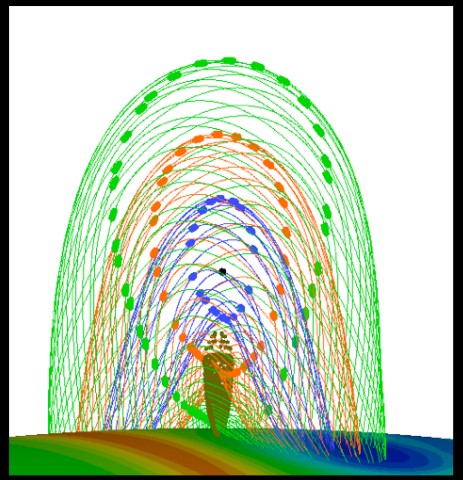
Thermodynamic and/or topological interfaces associated with nested toroidal flux surfaces



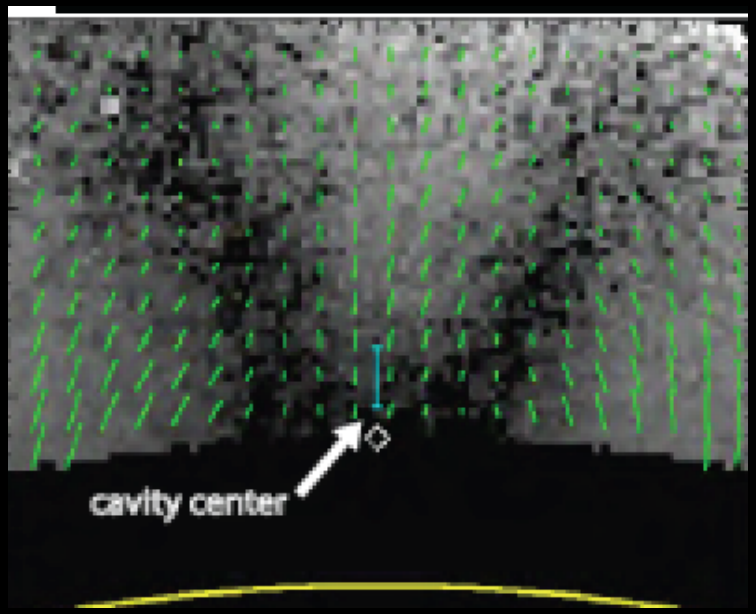
Tether-cutting reconnection (only for immediately pre-eruption?)

Field line length/geometry



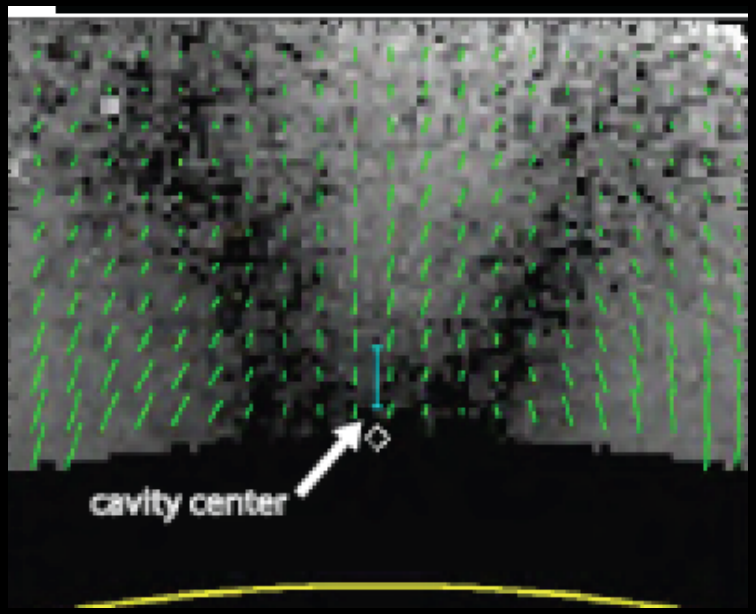


Conclusions: Lagomorphs



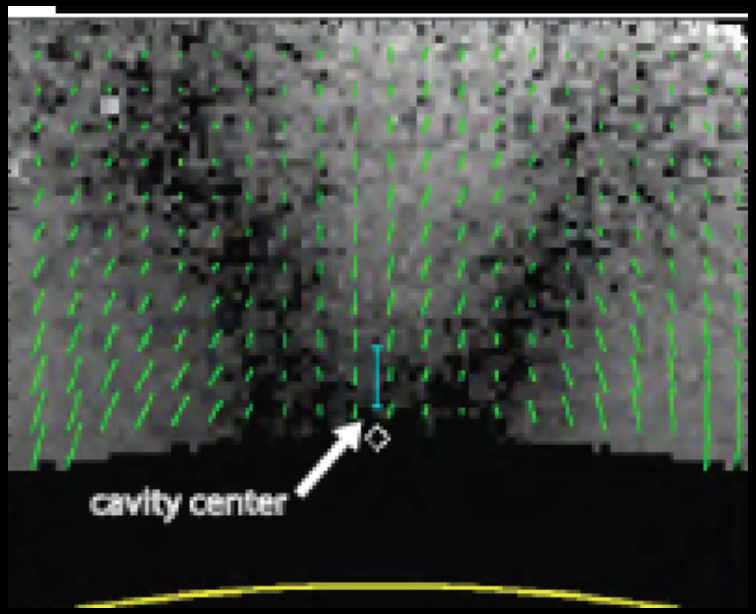
Conclusions: Lagomorphs

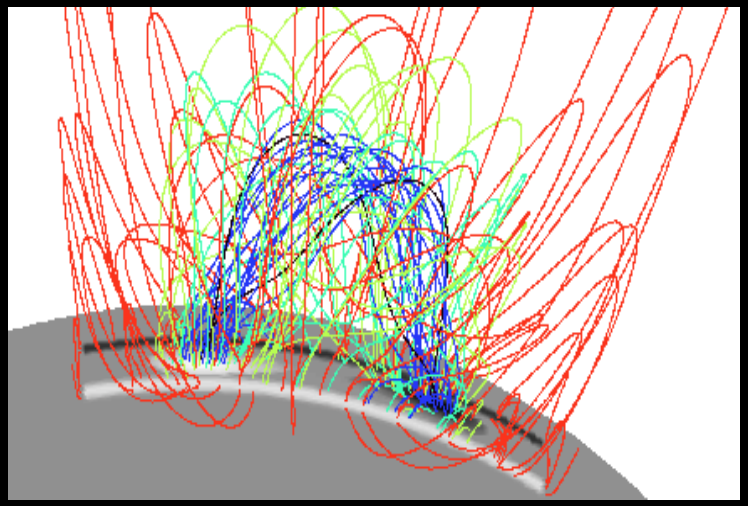
Axial field surrounded by poloidal field (flux rope)

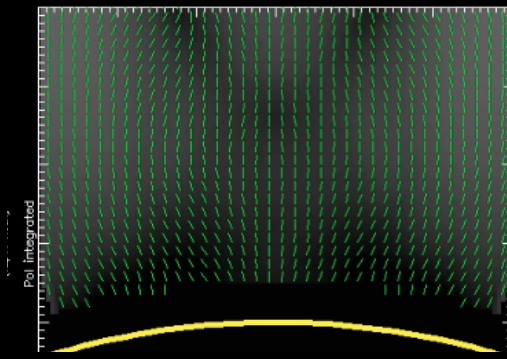


Conclusions: Lagomorphs

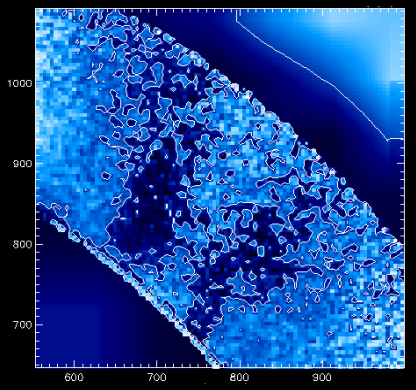
Axial field surrounded by poloidal field (flux rope)

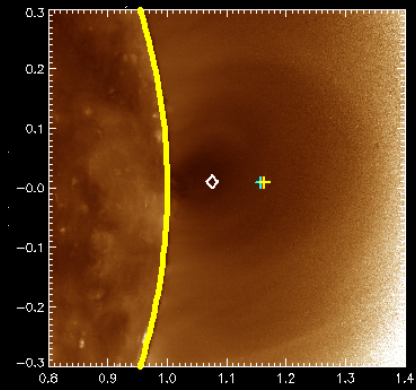




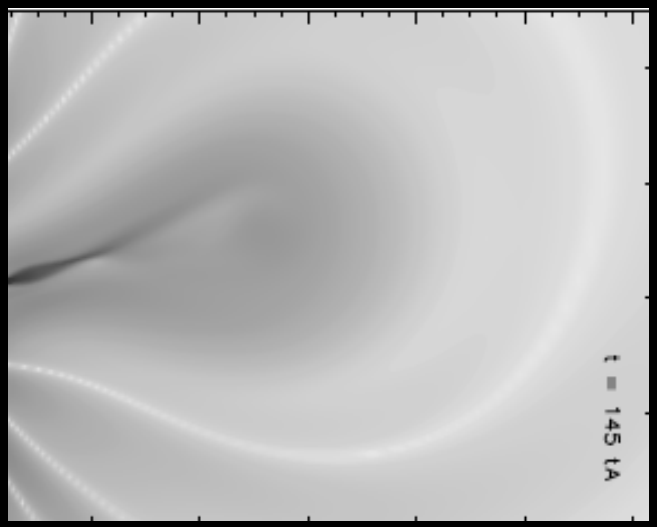


Can we use such observations to monitor topological changes?



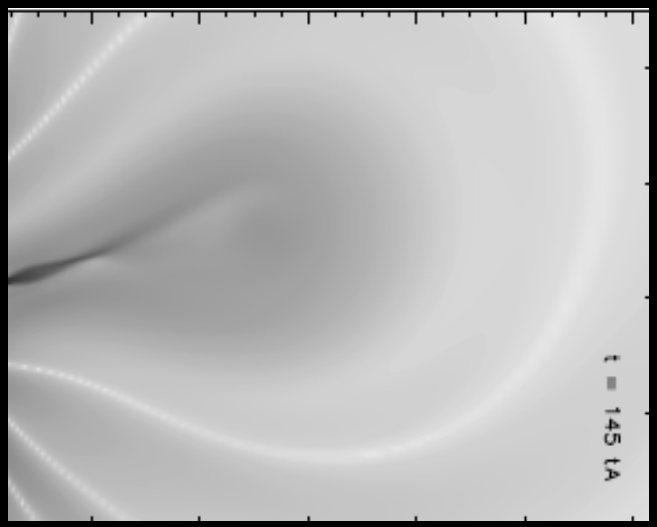


Conclusions: Liftoff



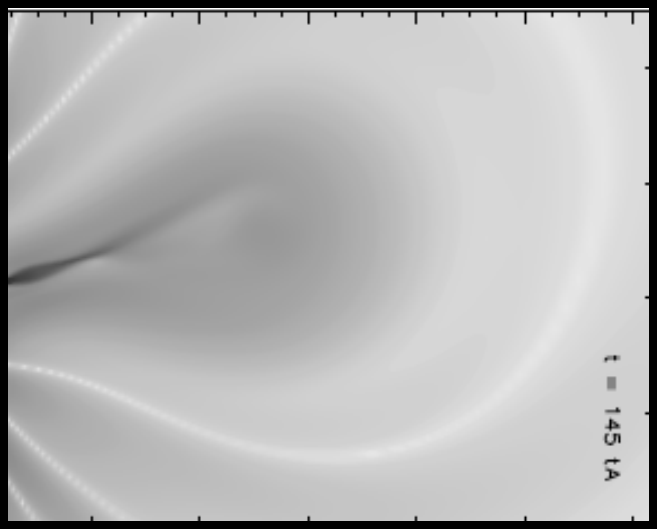
Conclusions: Liftoff

Topological changes leading up to ideal instability



Conclusions: Liftoff

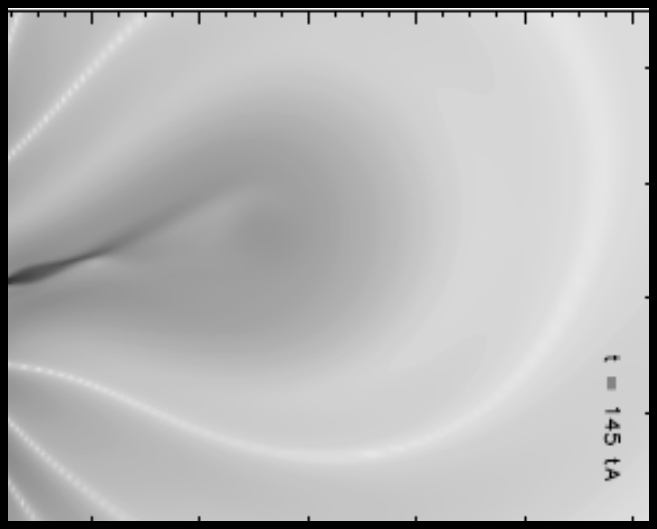
Topological changes leading up to ideal instability



Torus instability may be sufficient, but does not seem to be necessary for eruption.

Conclusions: Liftoff

Topological changes leading up to ideal instability

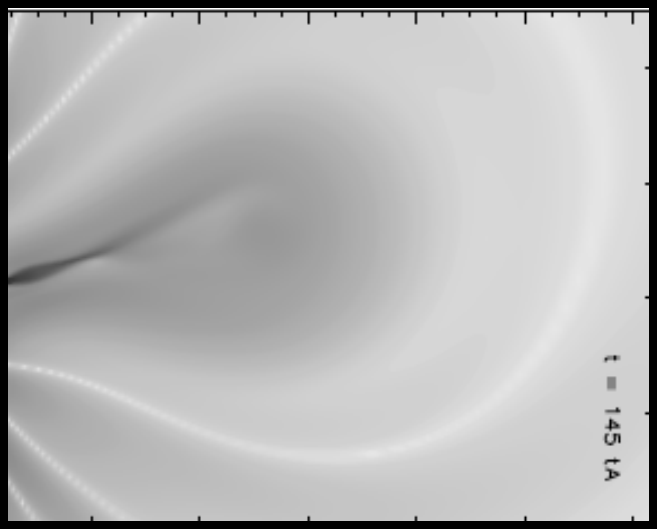


Torus instability may be sufficient, but does not seem to be necessary for eruption.

As we begin to measure the coronal fields themselves, is there a property: helicity, free energy, complexity, topology -- that we could measure to tell us that eruption is inevitable?

Conclusions: Liftoff

Topological changes leading up to ideal instability



Torus instability may be sufficient, but does not seem to be necessary for eruption.

As we begin to measure the coronal fields themselves, is there a property: helicity, free energy, complexity, topology -- that we could measure to tell us that eruption is inevitable?

Or do we have to wait till we can specify the full 3D coronal field and poke it to see what blows?