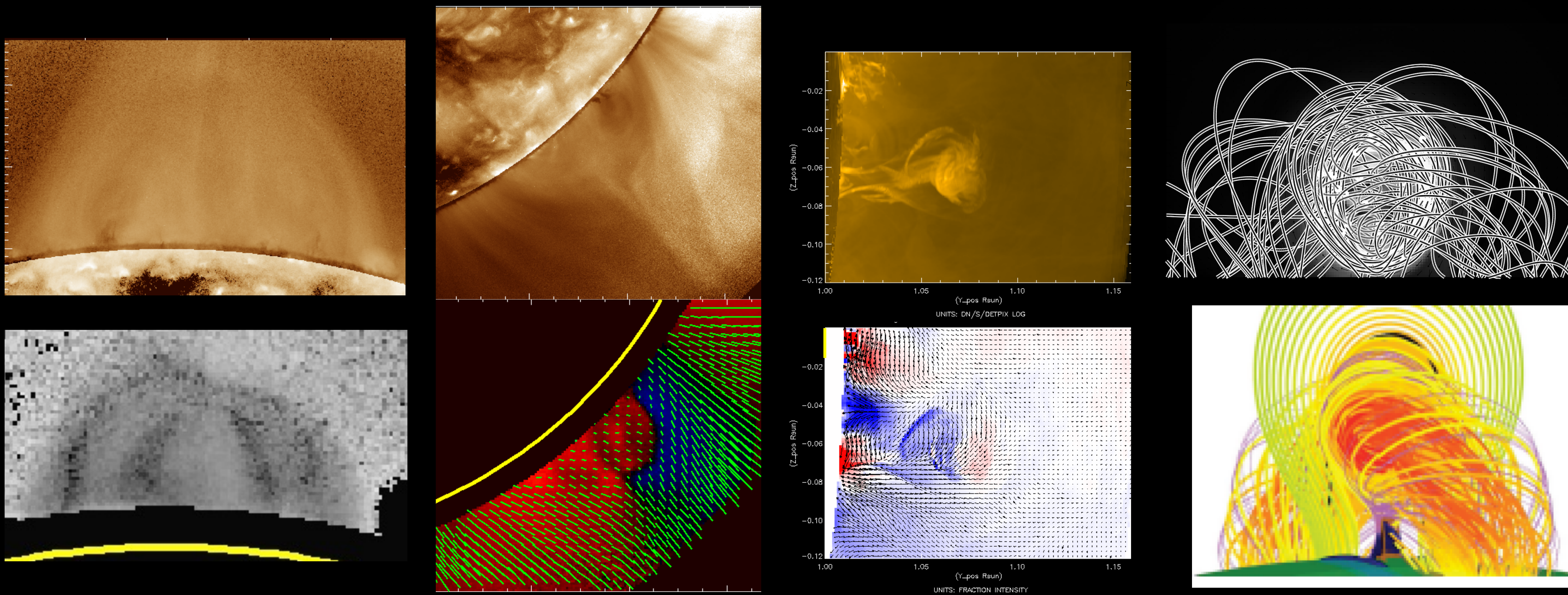
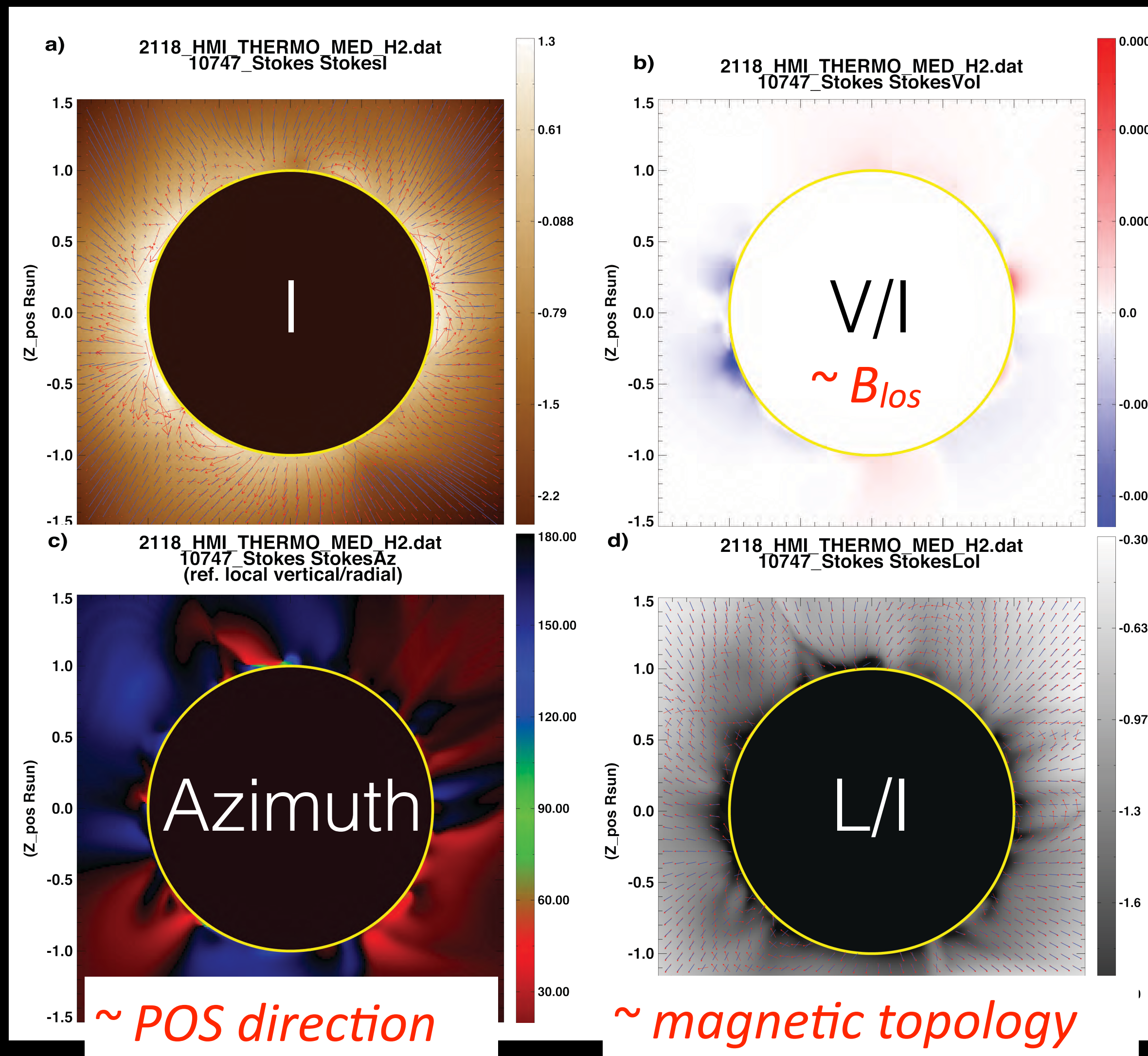
Data-Optimized Coronal Magnetic Field Model (DOC-FM): Recent results and progress



Sarah E Gibson, Marcel Corchado Albelo, Ed Deluca, Kévin Dalmasse, Giuliana de Toma, Yuhong Fan, Duncan Mackay, Kenzie Nimmo, Nishu Karna, Matthias Rempel, Antonia Savcheva, Steve Tomczyk
Doug Nychka, Natasha Flyer, Anna Malanushenko, Nathaniel Mathews

Coronal polarimetry

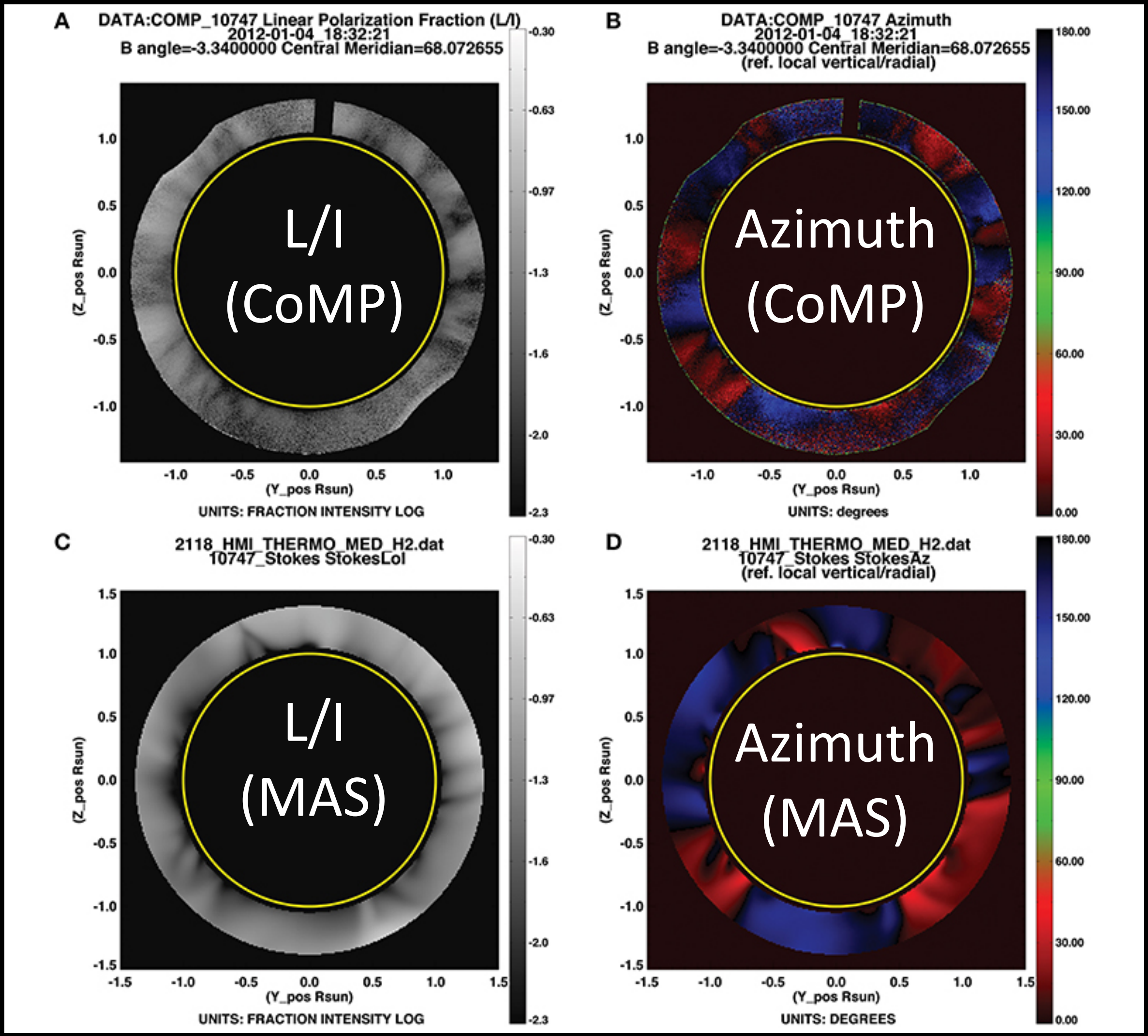


Polarization (Zeeman, saturated Hanle)

MAS model —> FORWARD

Gibson et al. 2016

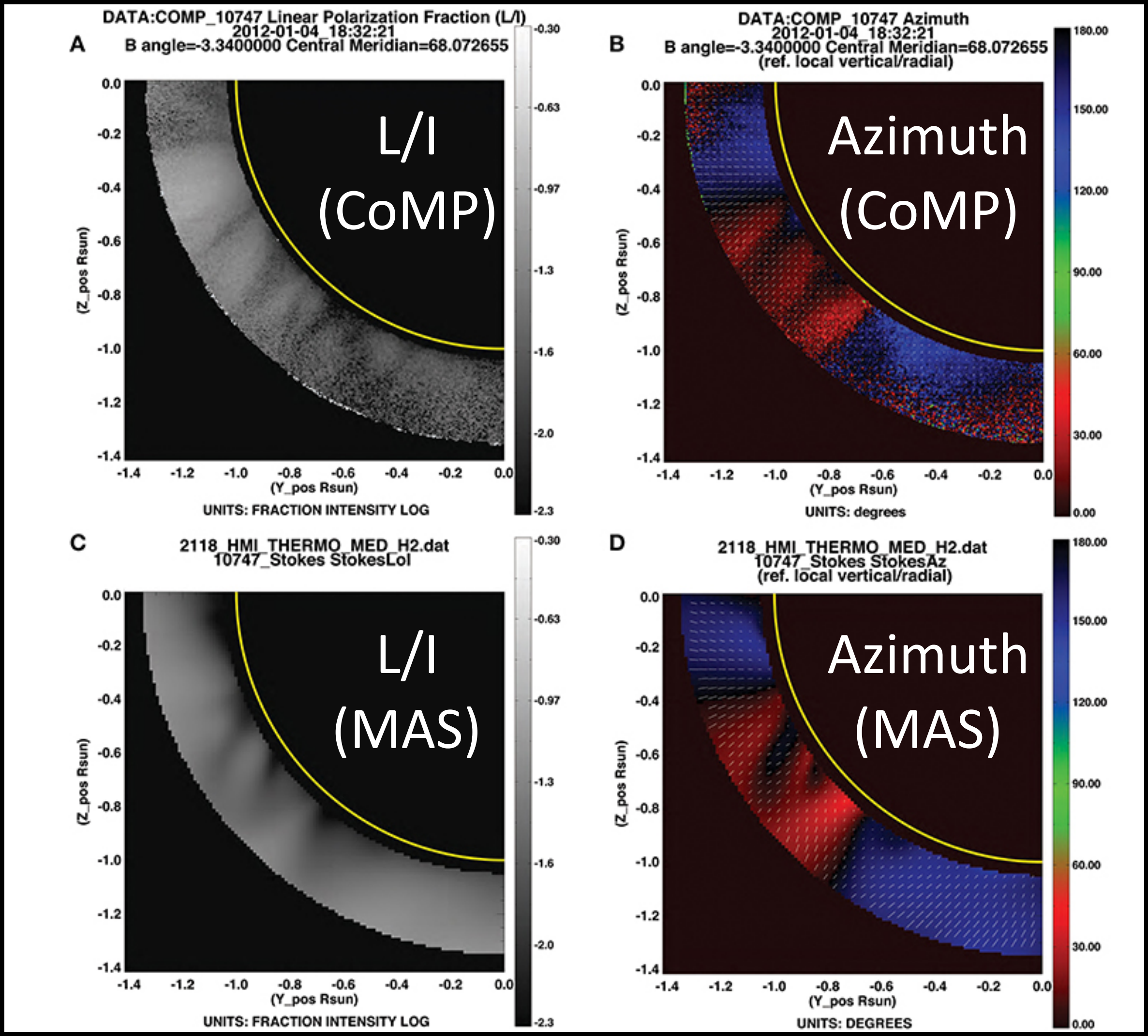
CoMP Observations



Linear polarization (percent and direction)

Gibson et al. 2016

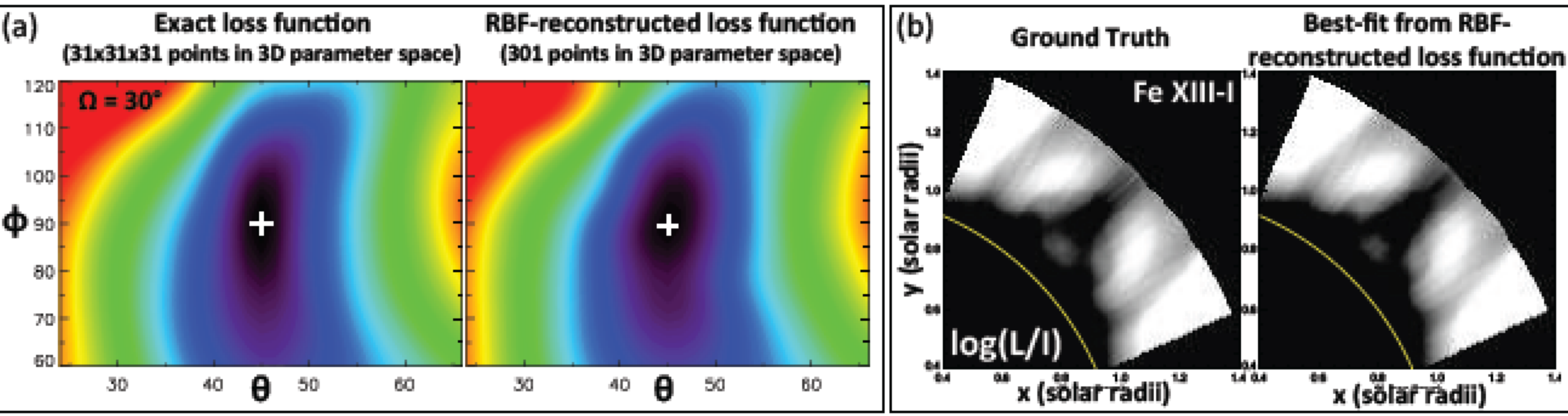
Model Validation…



Linear polarization (percent and direction)

Gibson et al. 2016

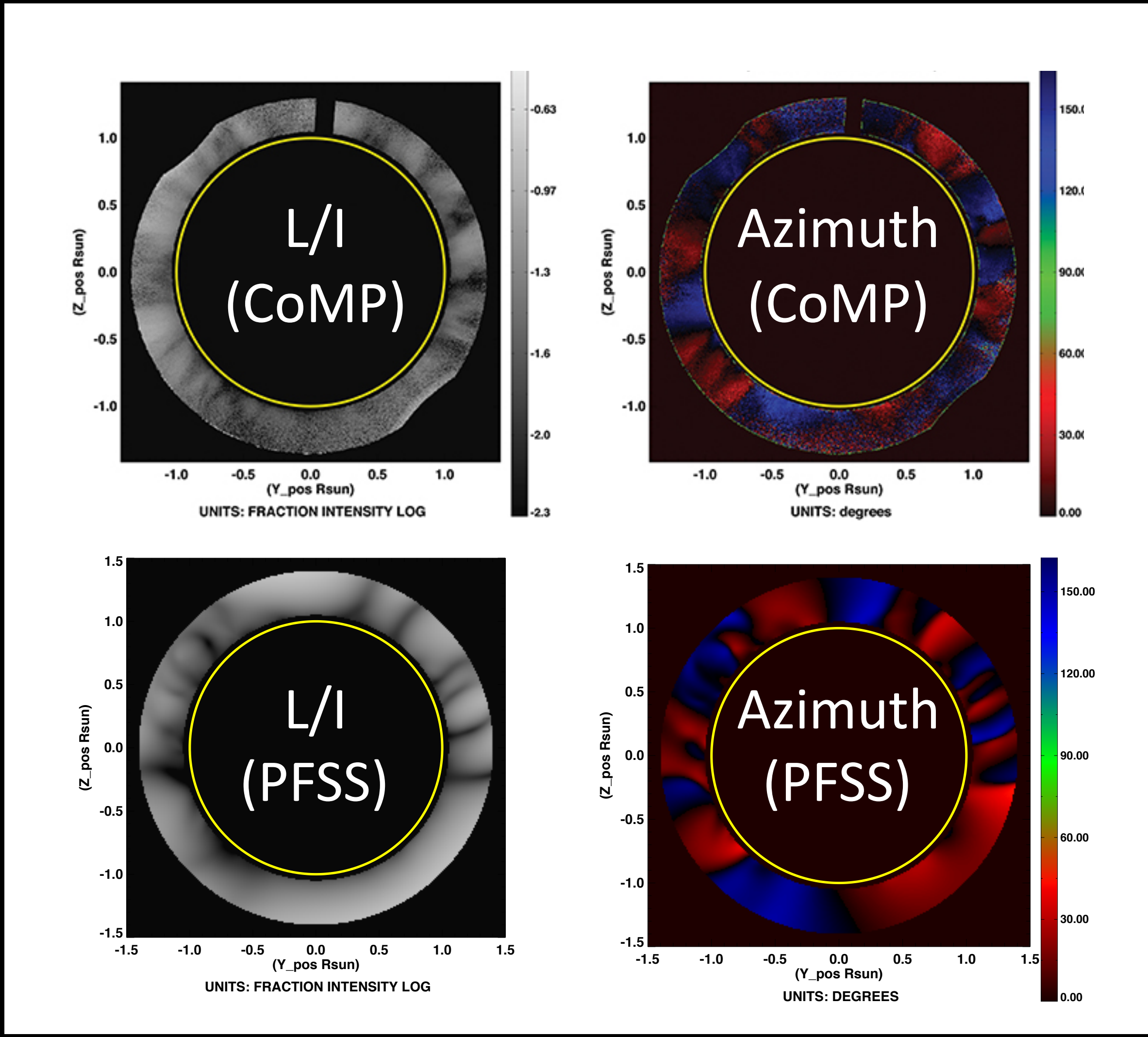
Model Optimization…



Stokes parameters used in loss function (generalization of e.g. chi-squared, a.k.a likelihood)

Dalmasse et al. 2016

Quantify non-potentiality?



Linear polarization (percent and direction)

How to use this new polarimetric diagnostic

Identify **how/where measurements are sensitive** to coronal magnetic fields

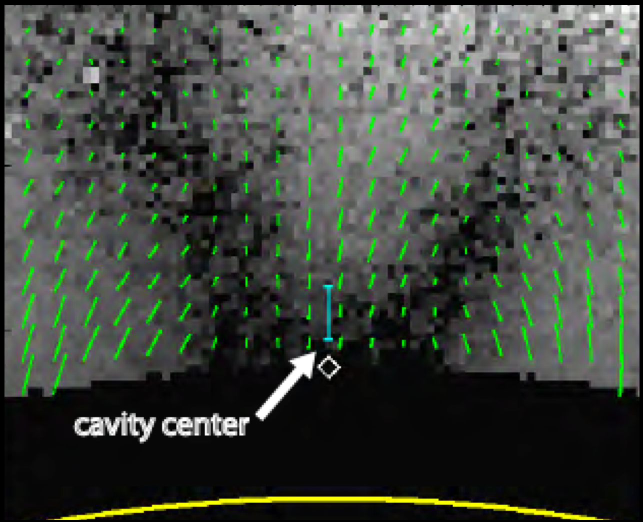
Establish **quantitative measures** of that sensitivity

Use these measures to help **optimize coronal magnetic models**

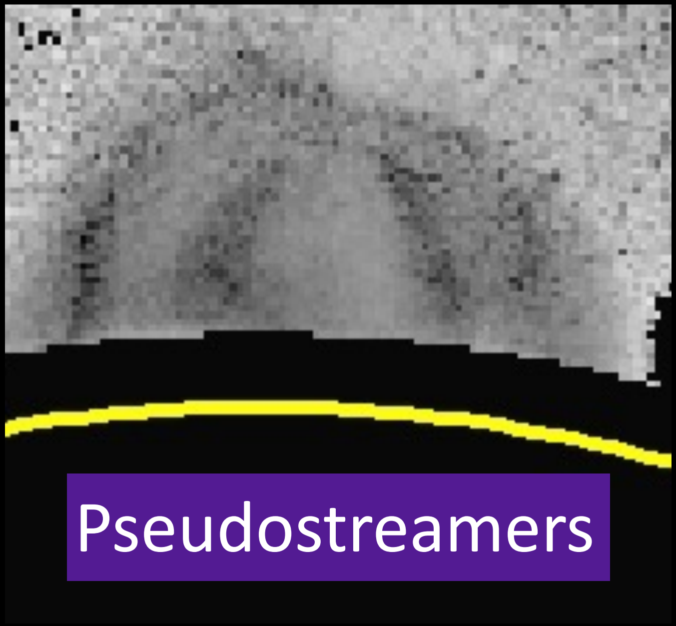
Test **robustness** to different models

Determine usefulness for **prediction** using **observations**

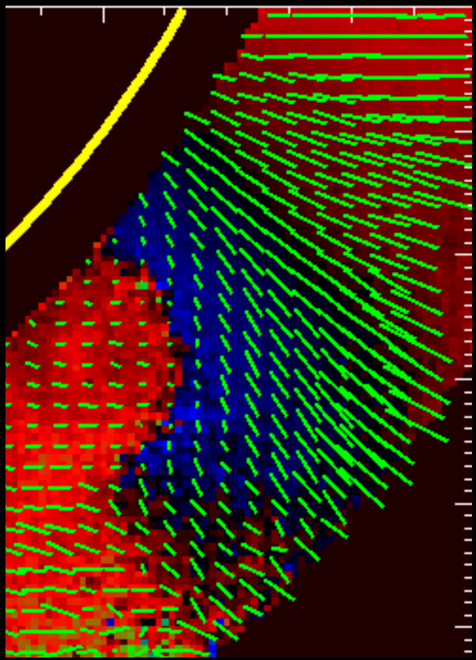
CoMP linear polarization: Sensitivity to magnetic fields



Magnetic flux ropes

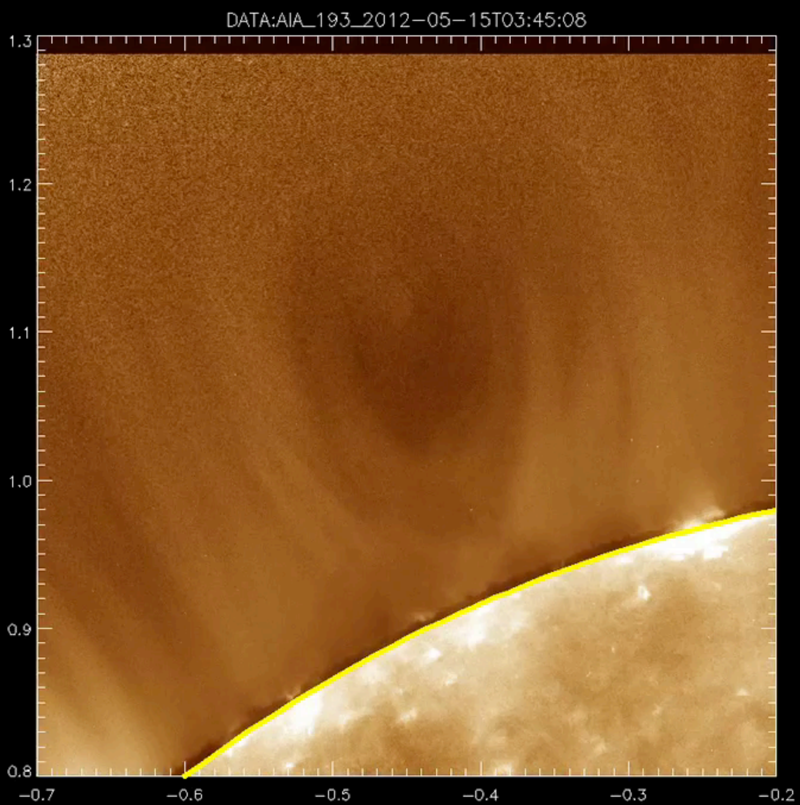


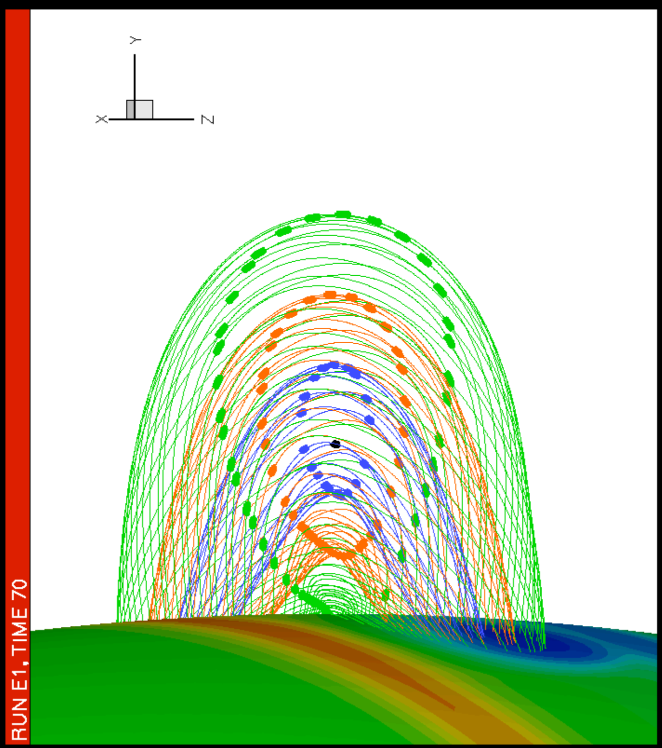
Pseudostreamers



Non-radial expansion

Cavities and flux ropes

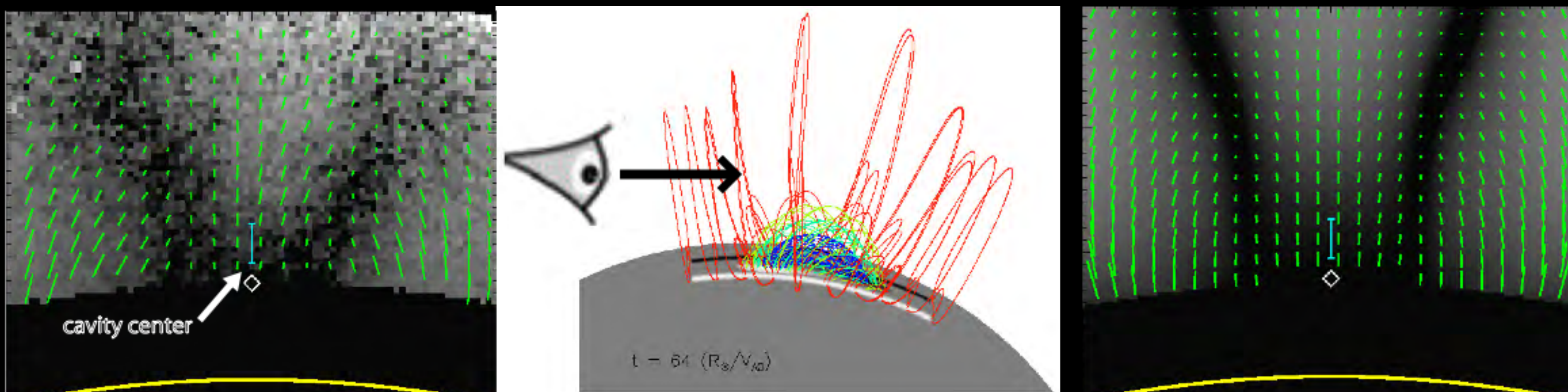




Lagomorphs, cavities and flux ropes

DATA

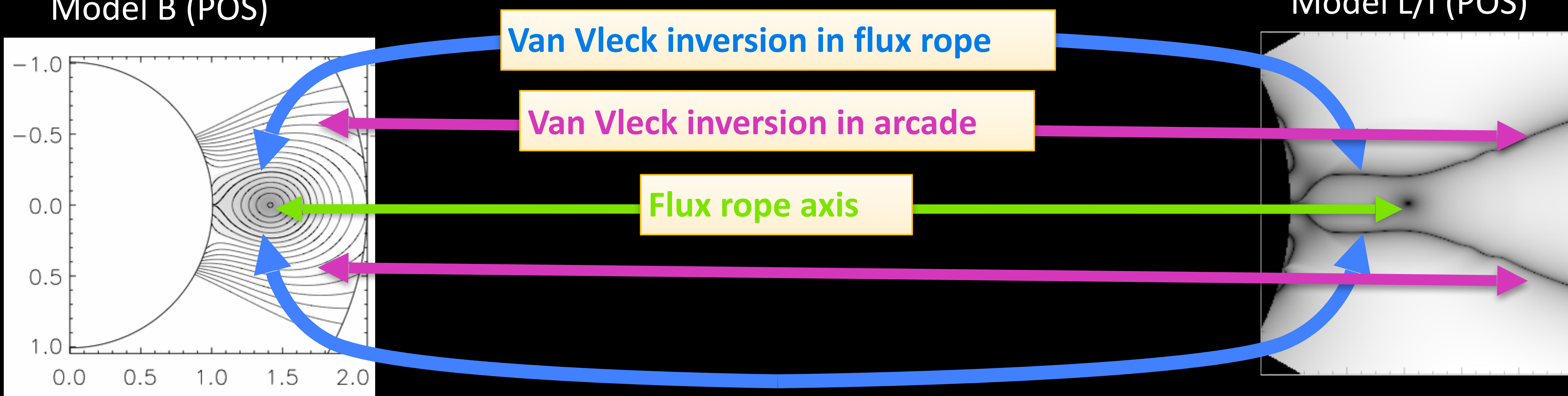
MODEL



Diagnostic of magnetic flux rope

Model B (POS)

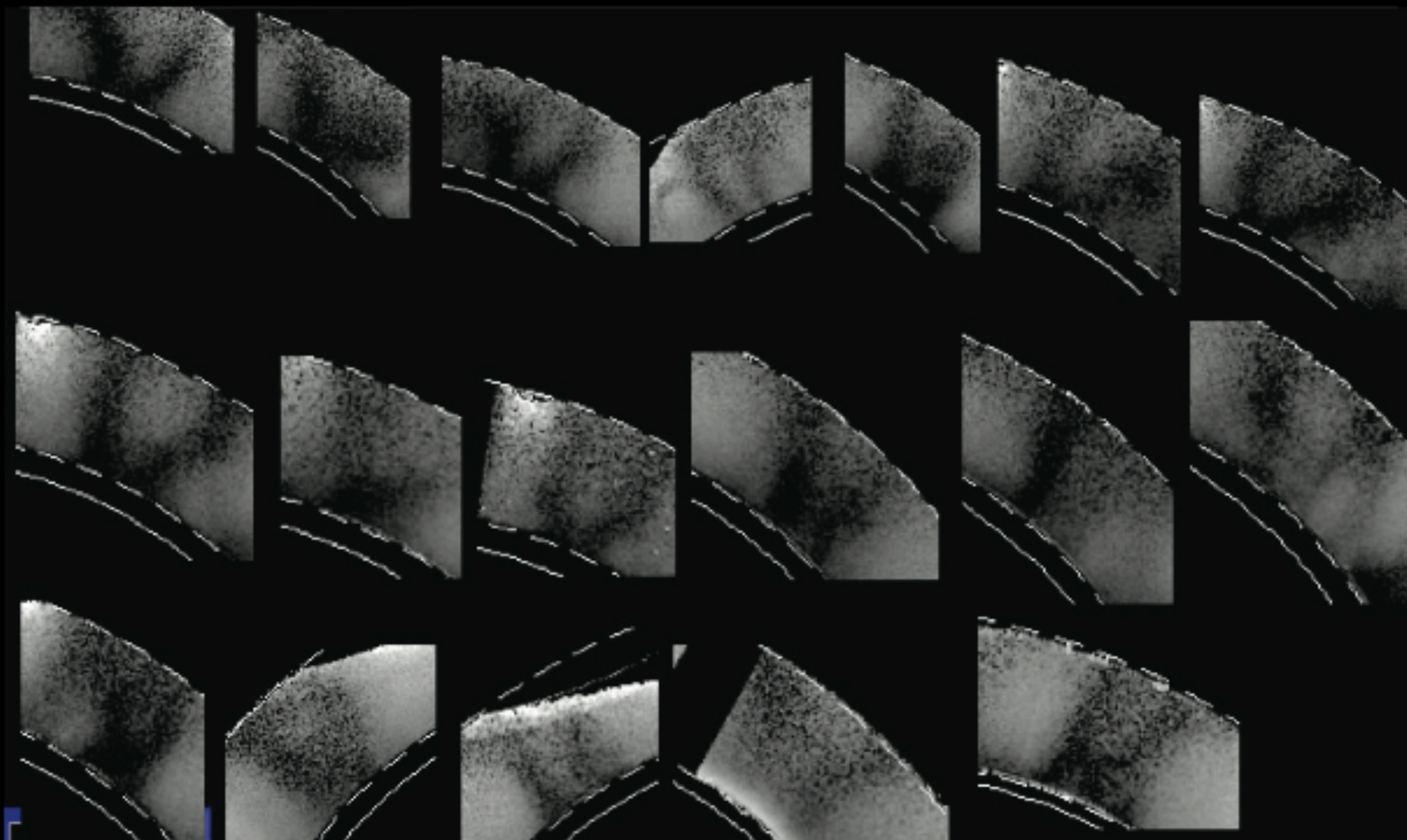
Model L/I (POS)



Bak-Steslicka et al., 2013

Lagomorphs, cavities and flux ropes

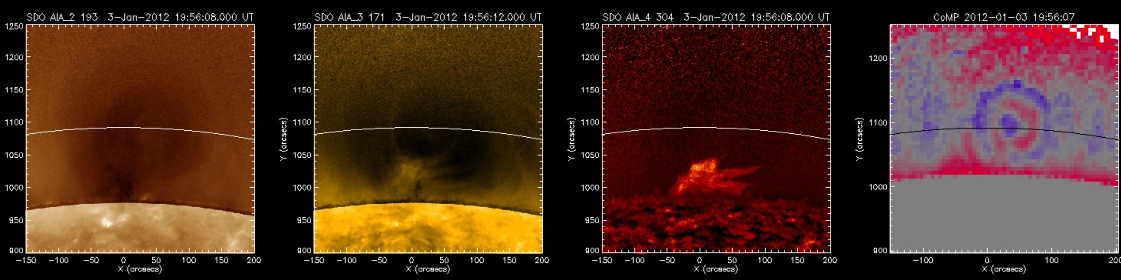
EUV coronal cavities = CoMP lagomorphs



Gibson, 2014

Lagomorphs, cavities and flux ropes

EUV coronal cavities = CoMP lagomorphs

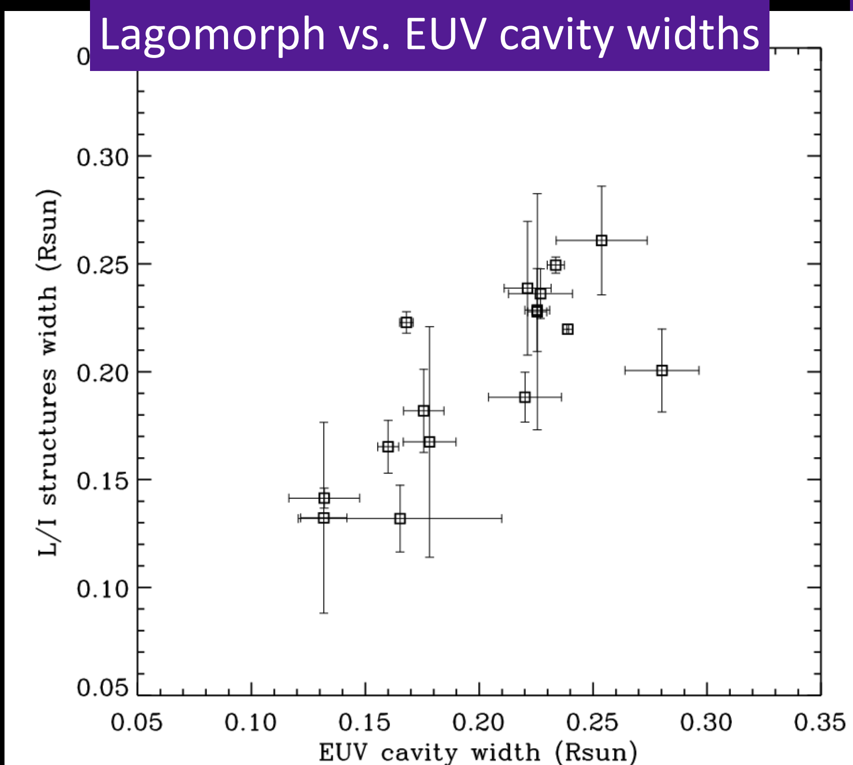


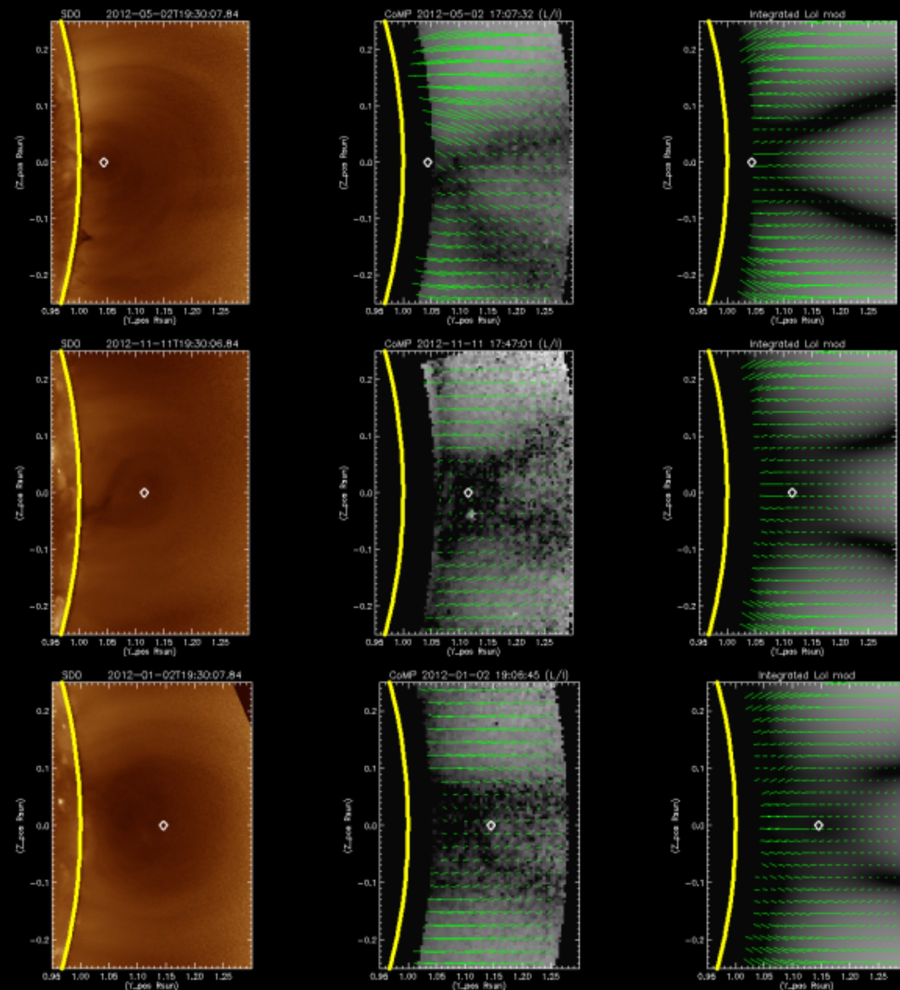
EUV cavity

Prominence

CoMP Doppler Vlos

Lagomorph vs. EUV cavity widths





EUV cavity

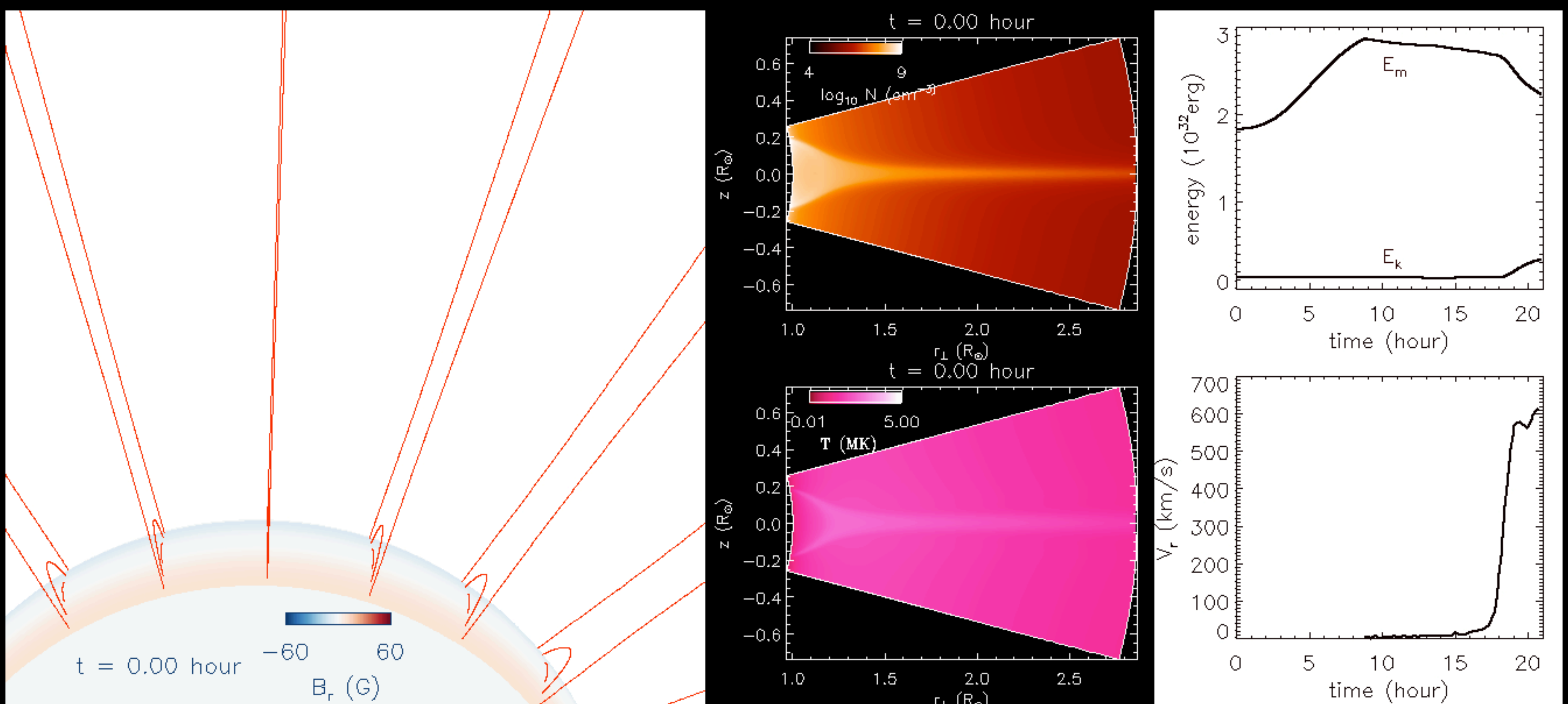
CoMP lagomorph

Forward-modeled flux ropes

Bak-Steslicka et al., 2014; 2016, Gibson, 2015; Fan, 2012

Free energy of evolving magnetic flux rope

- Twisted magnetic flux emerges (free energy increases)
- flux rope equilibrium (energy declines a little - num. diffusion)
- eruption (energy released)

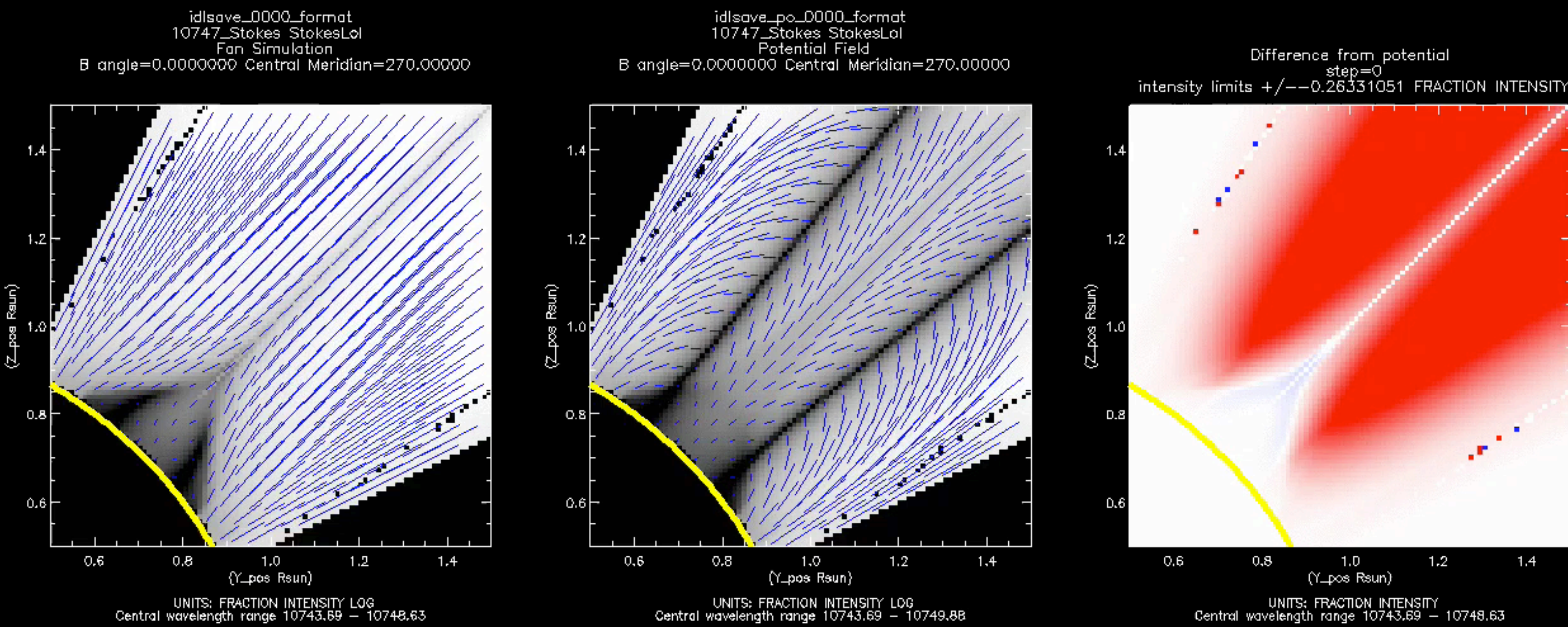


Fan, 2017

Linear polarization: measuring non-potentiality

Evolution during emergence phase

Simulation | Potential field - same boundary | Difference

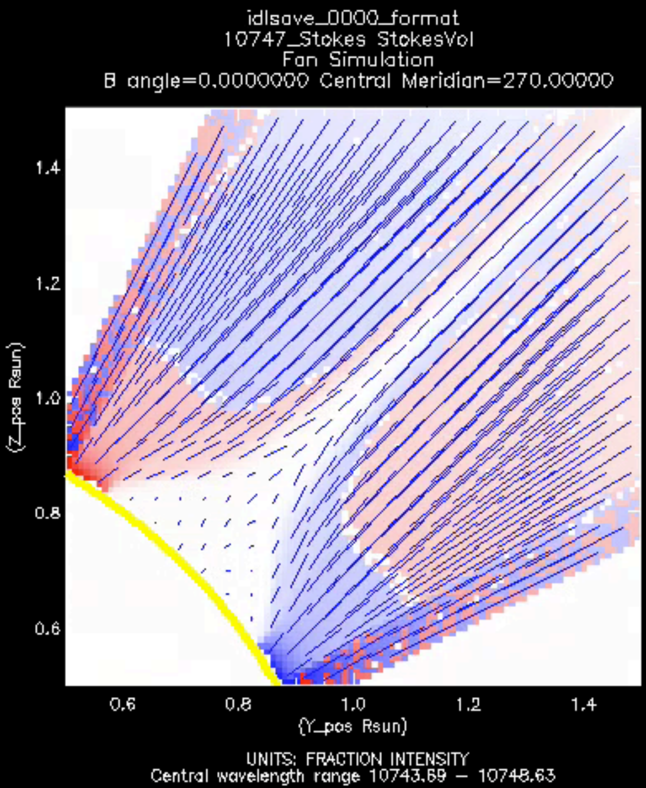


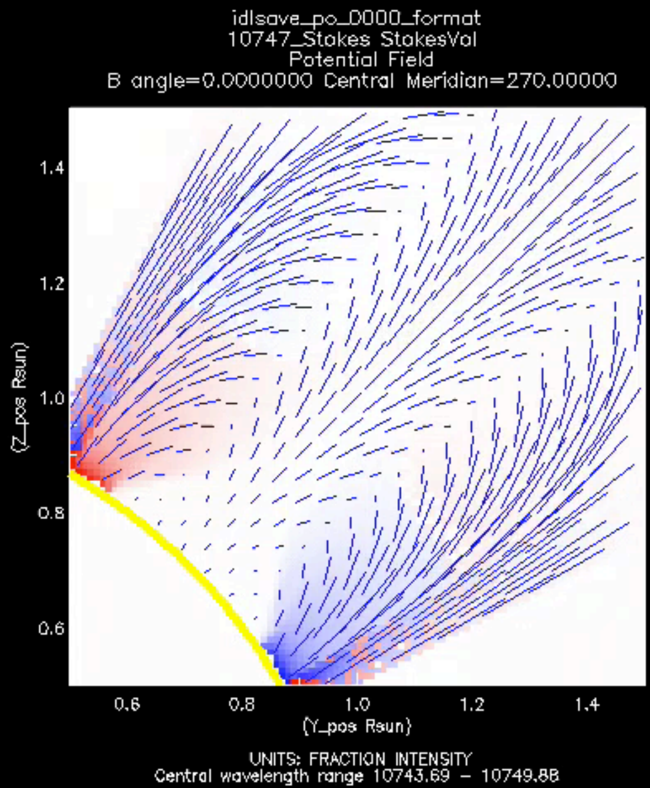
Summer project: SOARS undergraduate Marcel Corchado Albelo

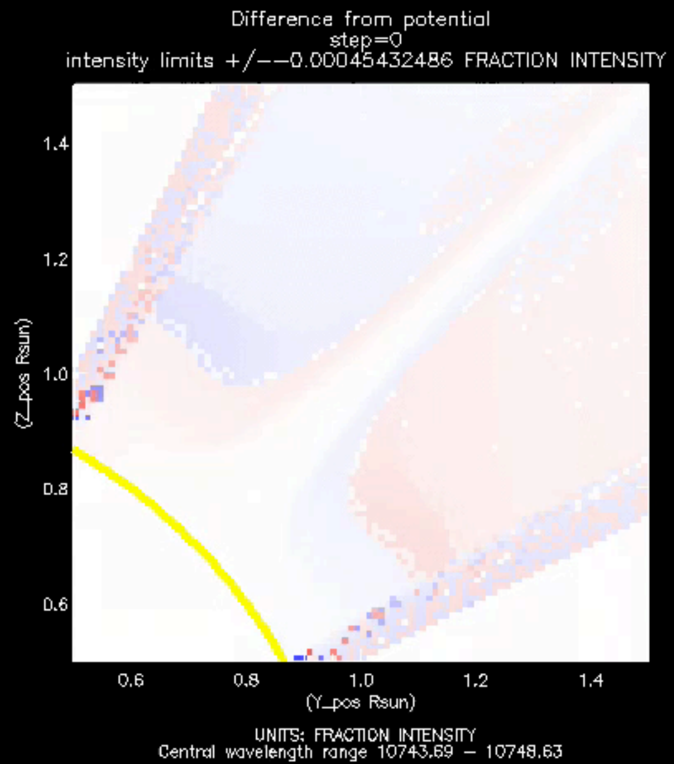
Circular polarization: measuring non-potentiality

Evolution during emergence phase

Simulation | Potential field - same boundary | Difference







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Circular polarization: measuring non-potentiality

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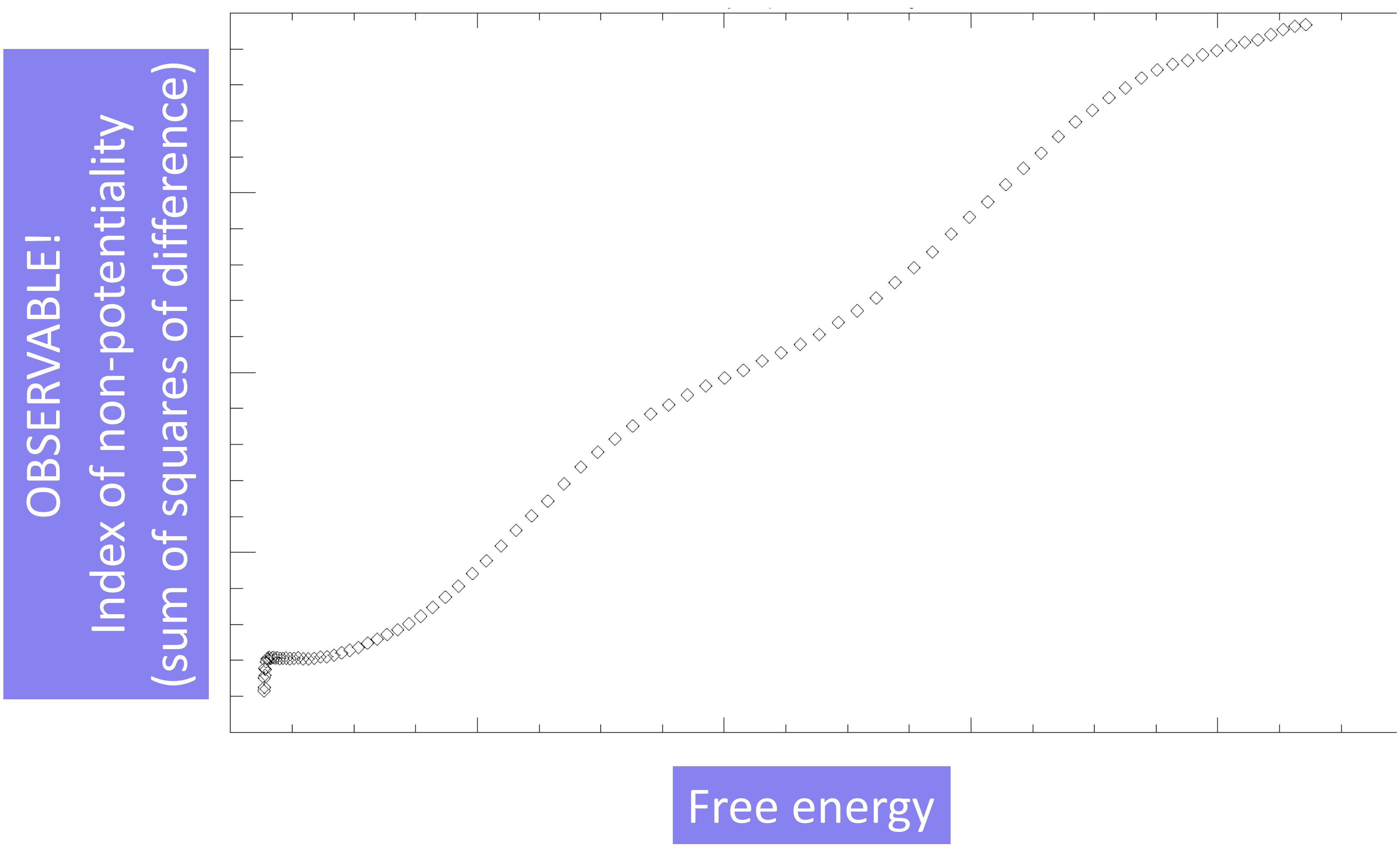

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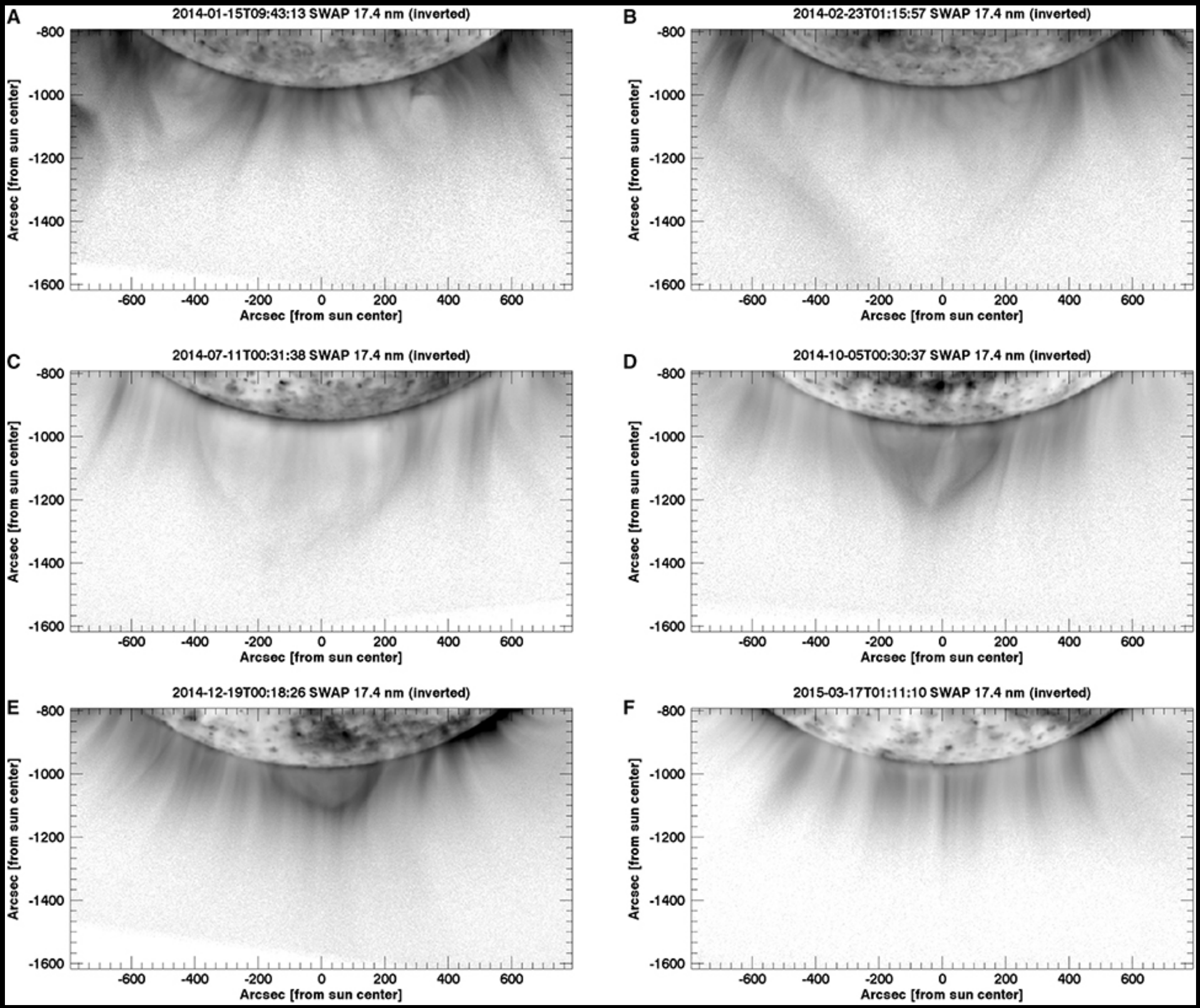
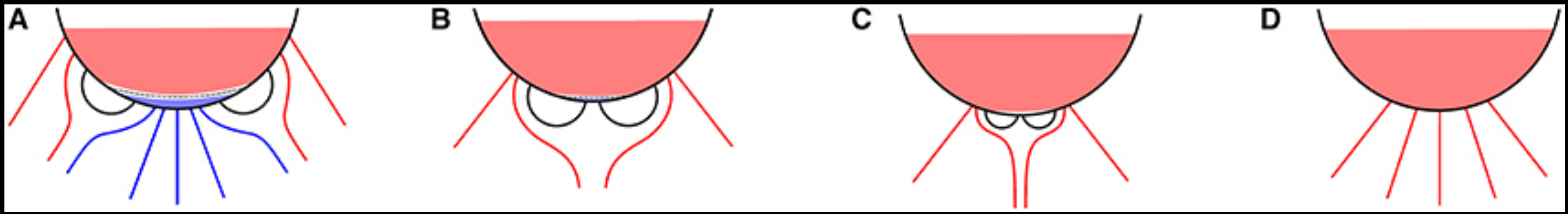
Pseudostreamers



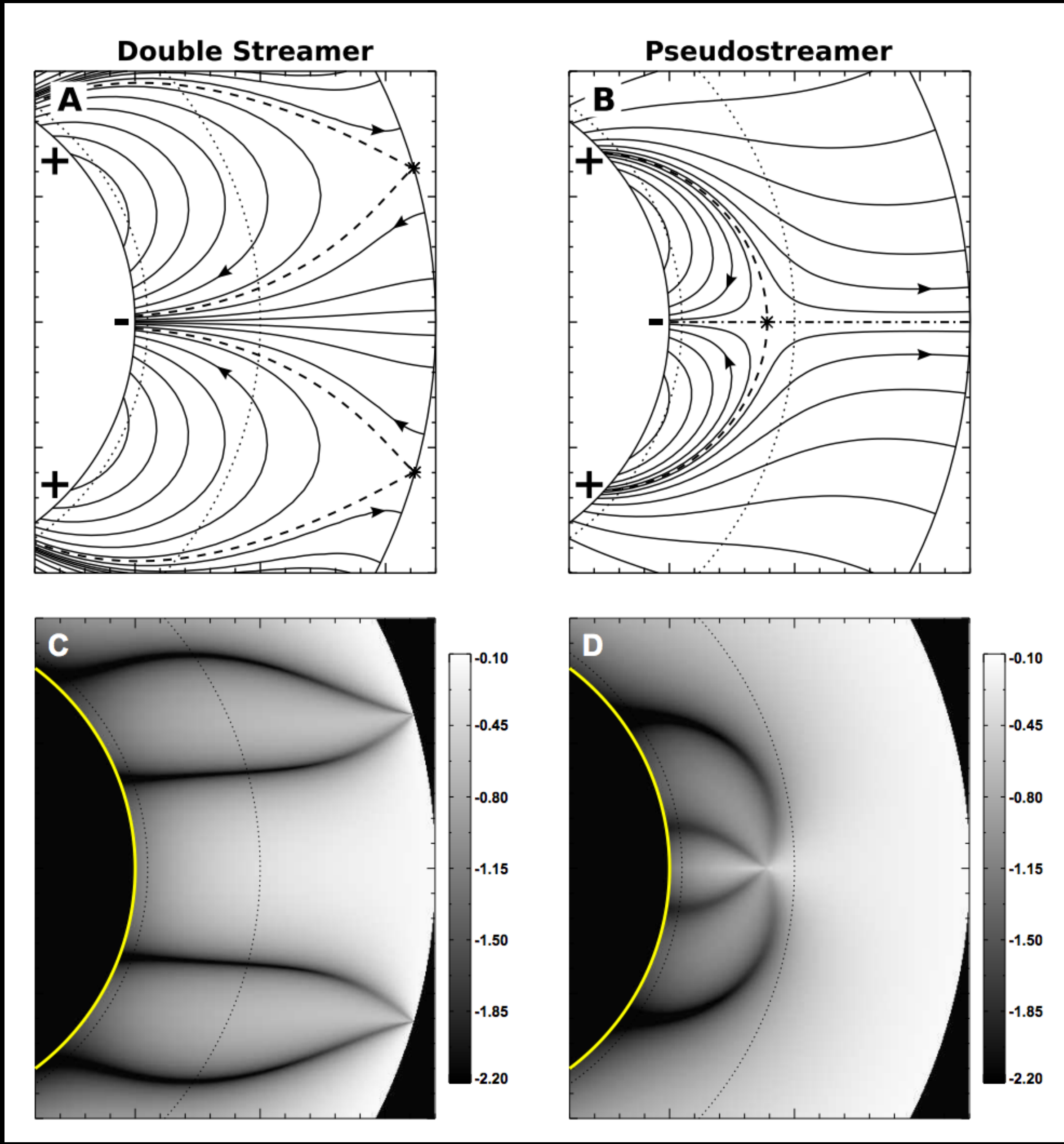
Evolution of a polar crown

Guennou et al 2016



Pseudostreamers in linear polarization

Expected topology



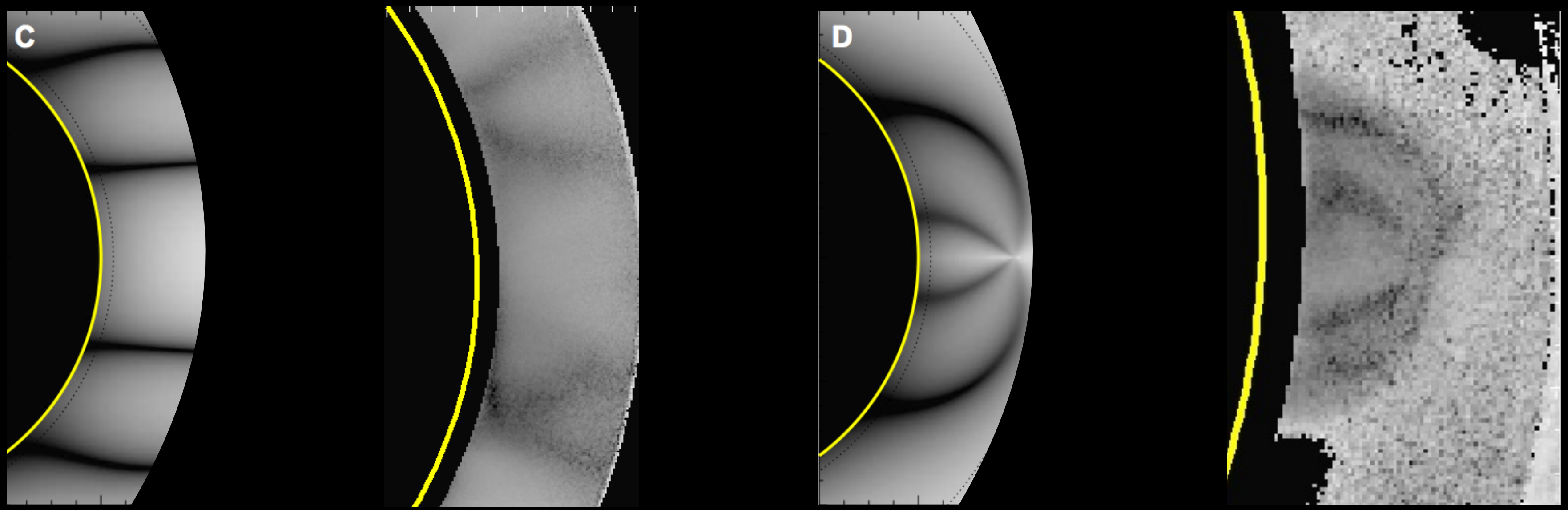
L/I

Rachmeler et al 2014

Pseudostreamers in linear polarization

CoMP observations vs models

L/I

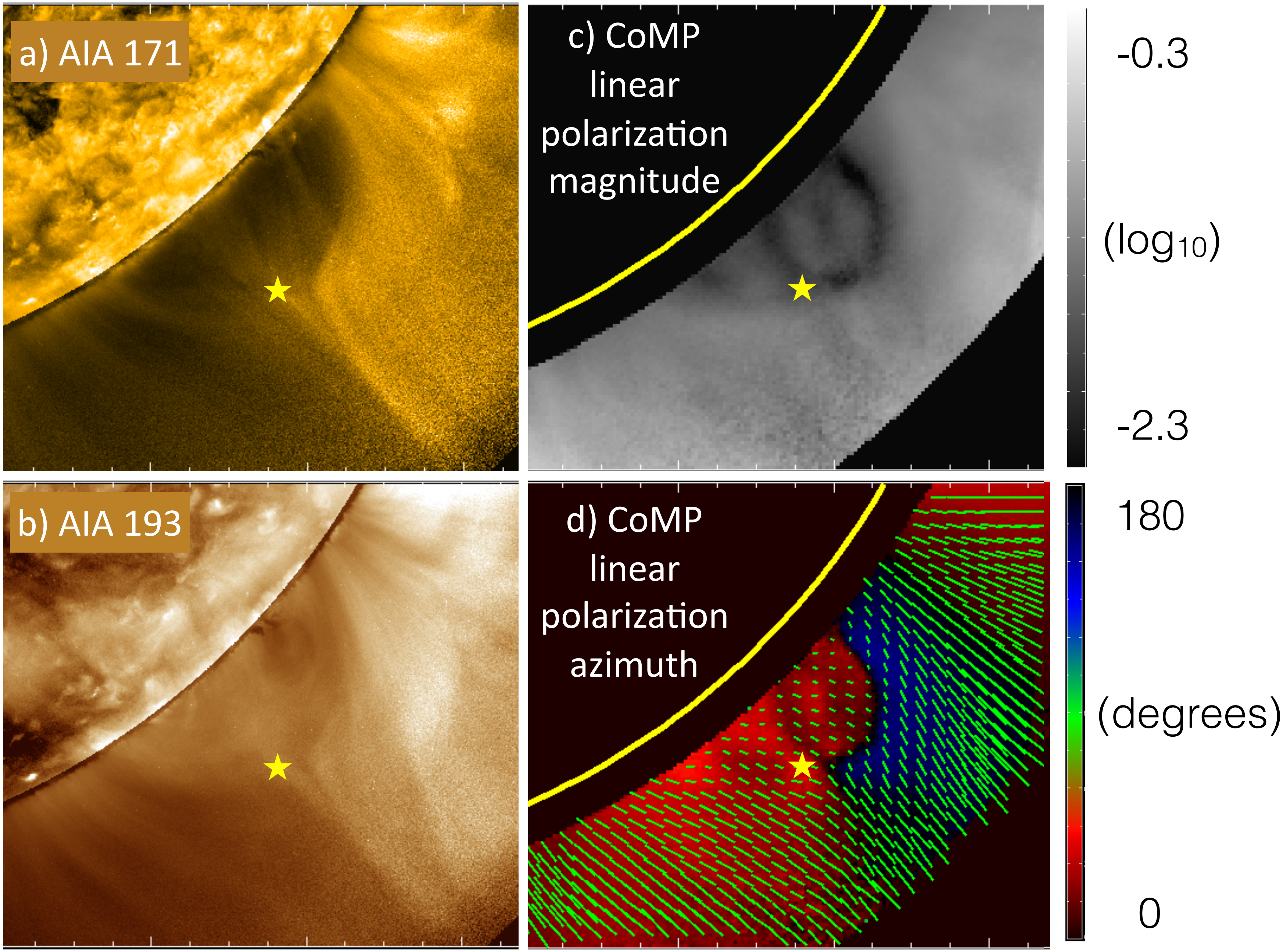


Double Streamer

Pseudostreamer

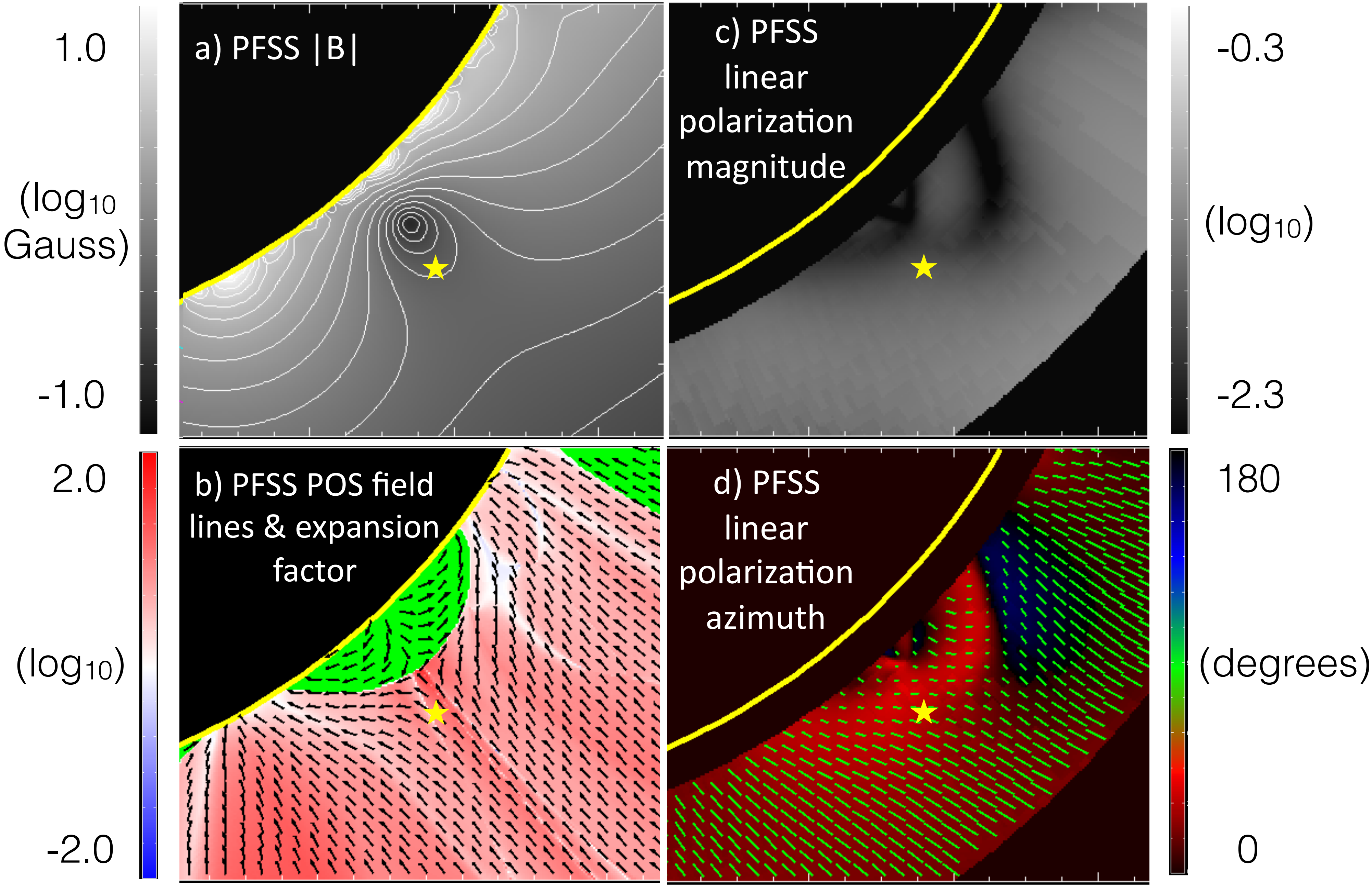
Gibson et al 2017; Rachmeler et al. in preparation

Pseudostreamers in linear polarization



Gibson et al., 2017

Pseudostreamers in linear polarization

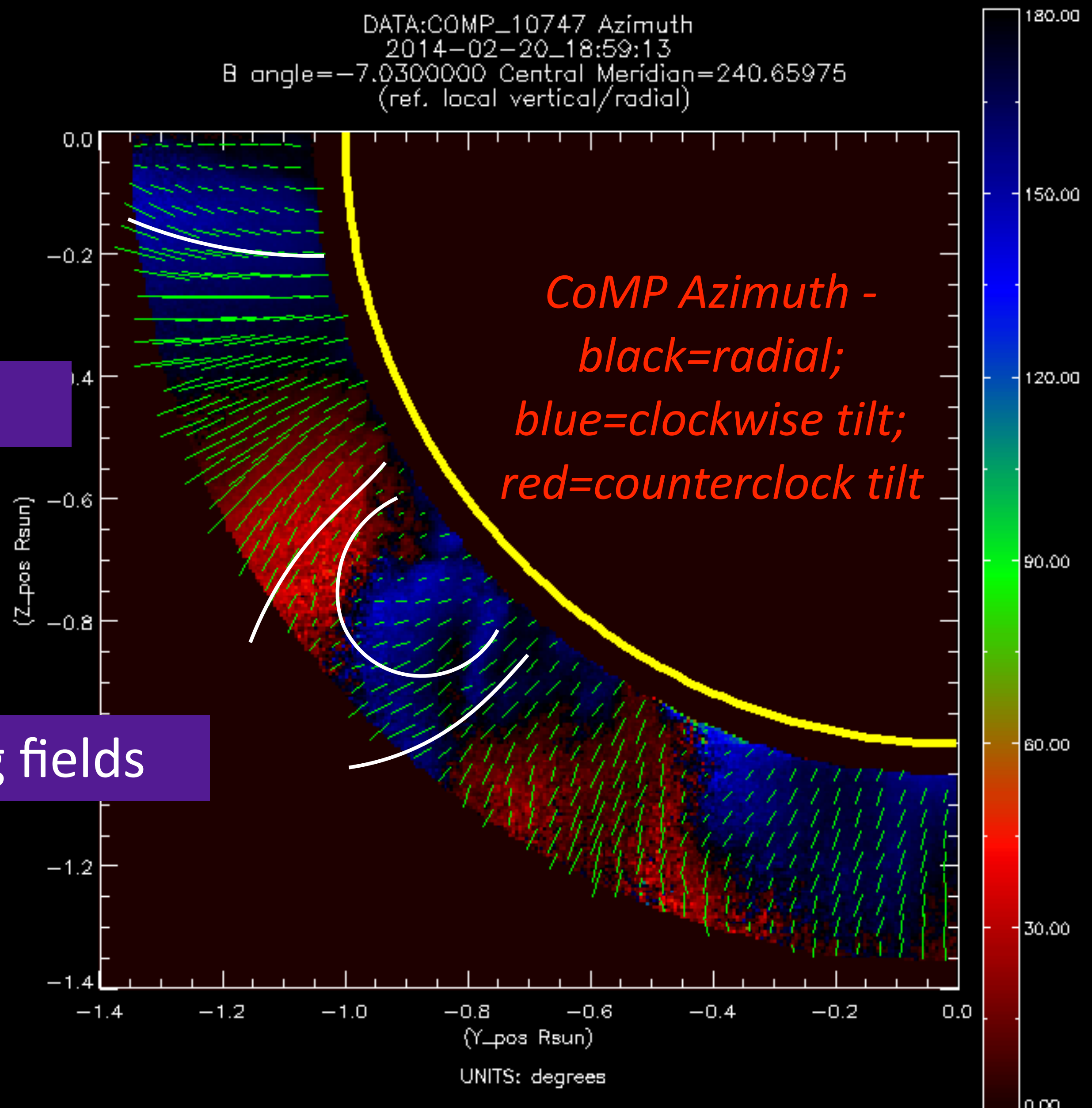


Potential field model null is lower than observed by CoMP

Non-radial expansion

diverging fields

converging fields

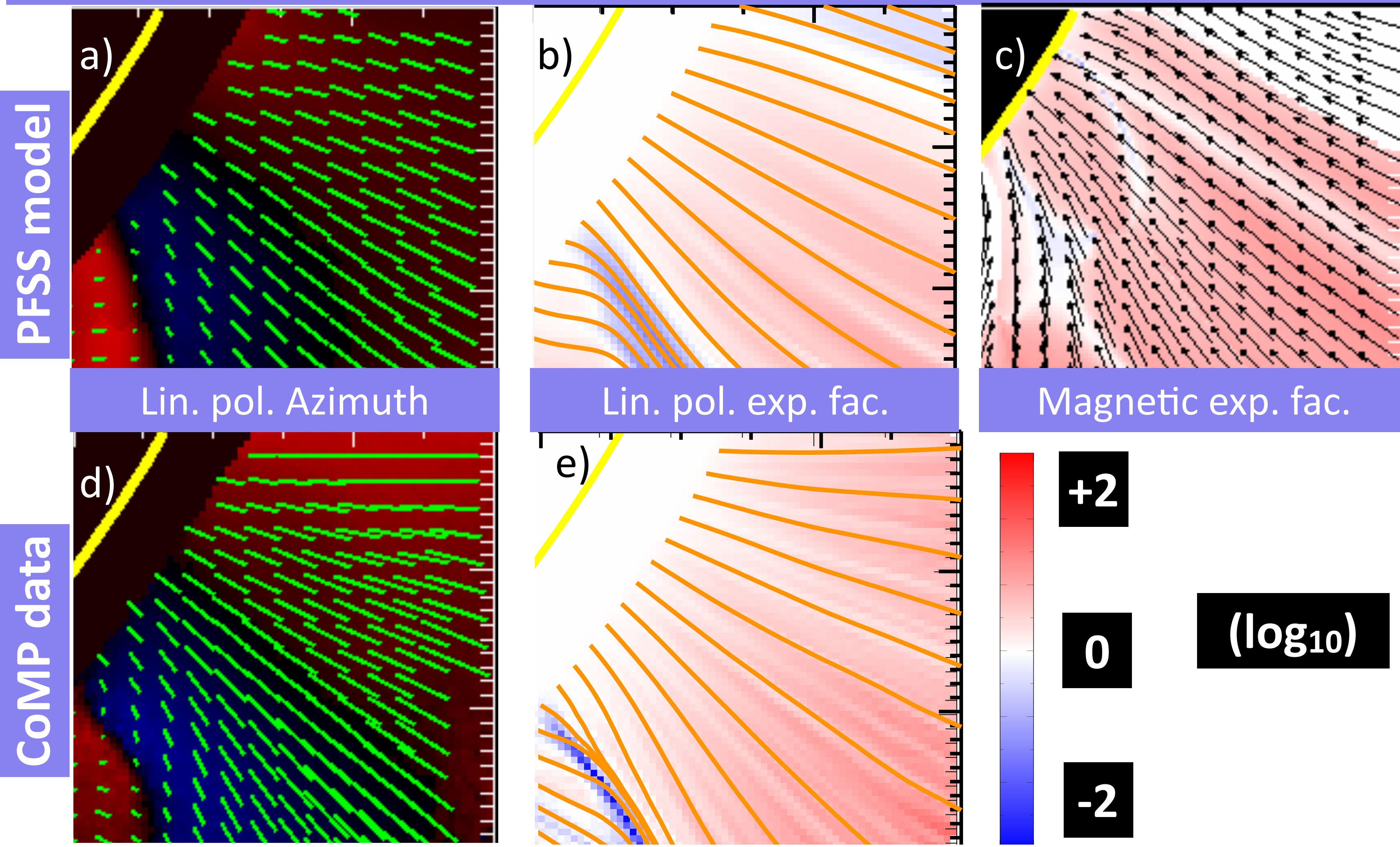


Non-radial expansion

Expansion factor associated with pseudo streamers is underestimated

Significant for solar wind acceleration models

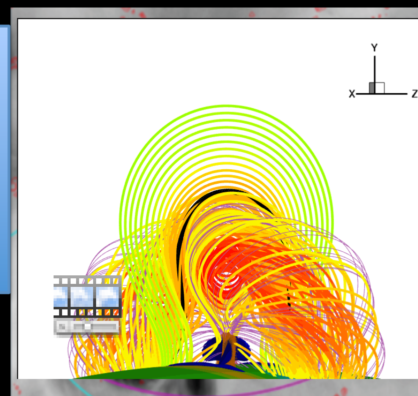
(*Wang et al. 2007; Riley & Luhmann, 2012; Wang et al. 2012*)



Data-optimized coronal field model (DOCFM)

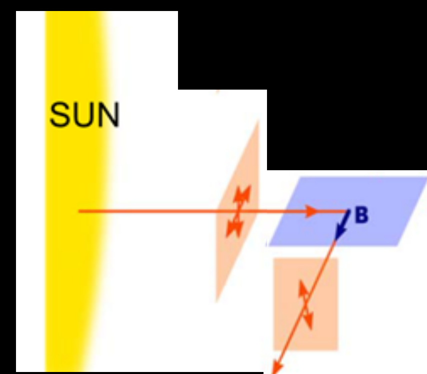
Coronal-model based approach to forward-fitting the global solar magnetic field (NCAR-CfA collaboration)

Parameterized model of the solar coronal *physical state* (magnetic field, density, temperature… Use priors!)

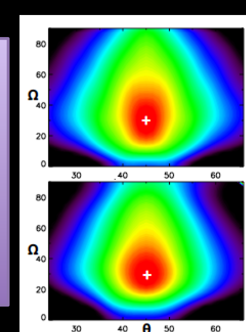


Maximize posterior

Forward operation of magnetically-sensitive *physical processes* on the physical state, resulting in synthetic polarimetric observations

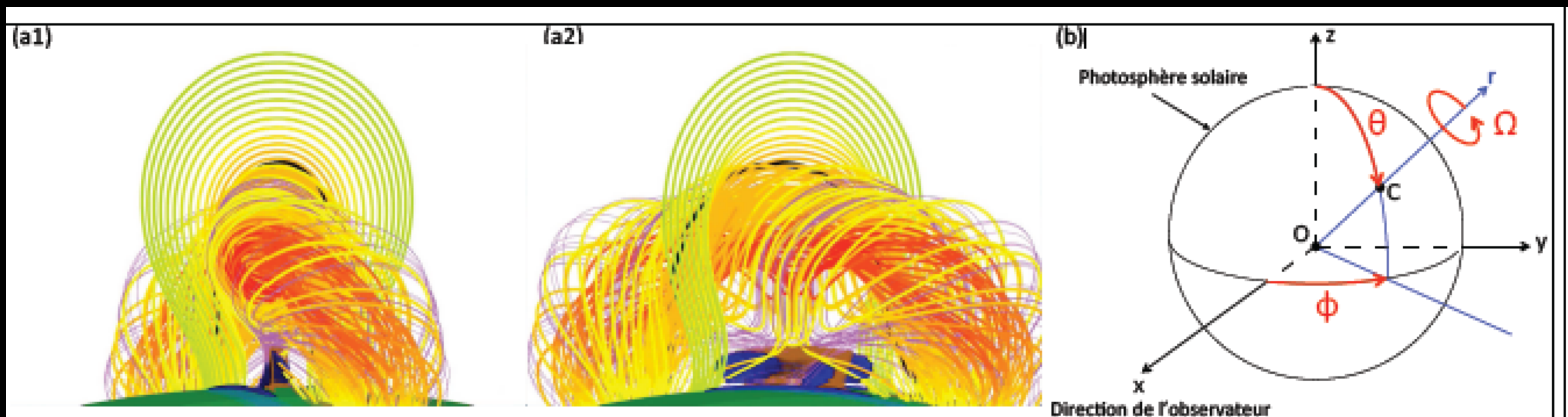


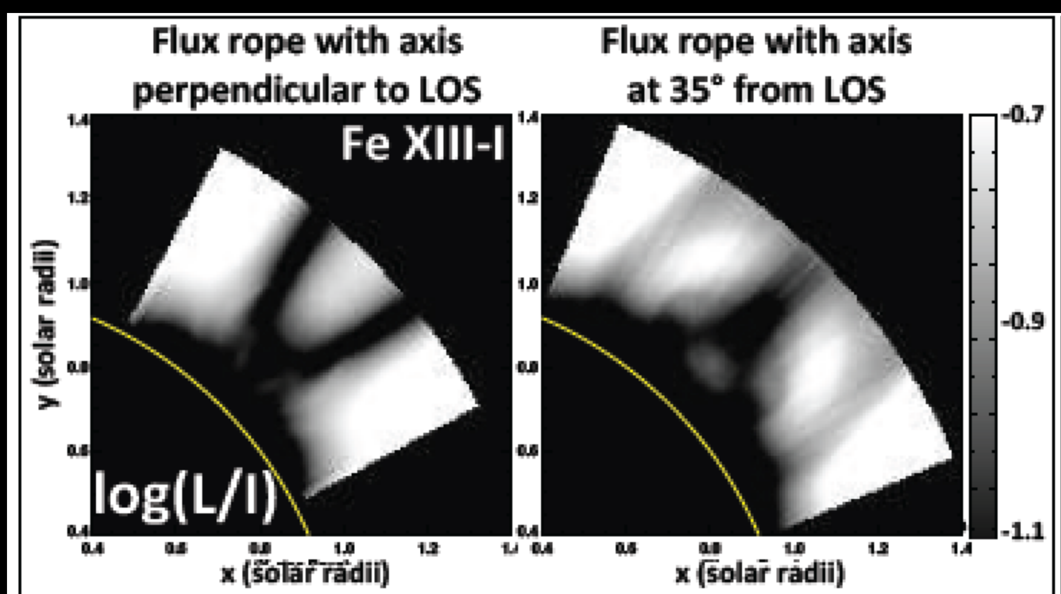
Calculation of likelihood comparing synthetic vs. measured observations – efficient statistical methods



Modify model

ROAM: Radial-basis-function Optimization Approximation Method





Using parameterized model, seek to regain "ground truth"

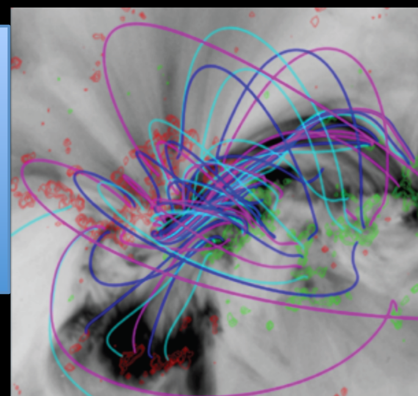
Efficient, radial-basis-function interpolant to speed up grid search

Dalmasse et al., 2016

Data-optimized coronal field model (DOCFM)

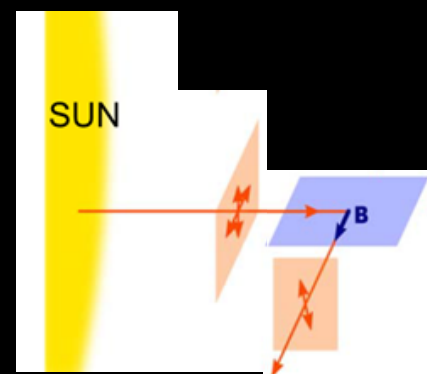
Coronal-model based approach to forward-fitting the global solar magnetic field (NCAR-CfA collaboration)

Parameterized model of the solar coronal *physical state* (magnetic field, density, temperature… Use priors!)



Maximize posterior

Forward operation of magnetically-sensitive *physical processes* on the physical state, resulting in synthetic polarimetric observations



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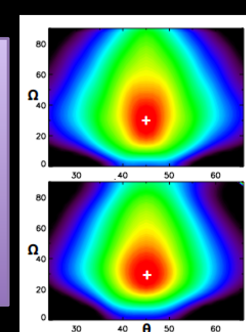


Modify model

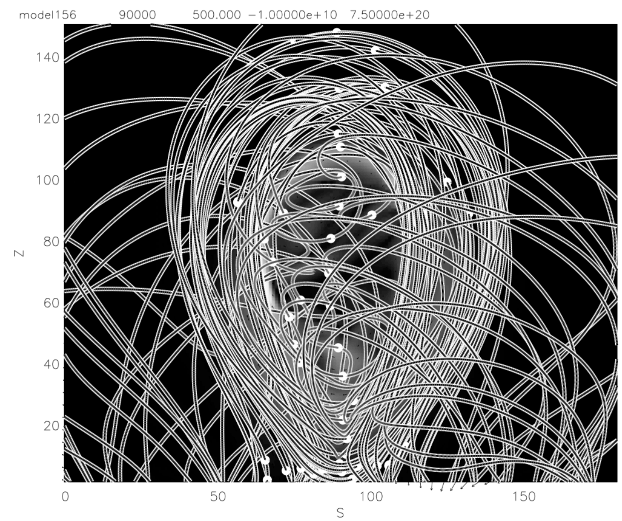
Flux-rope insertion: grid of solutions

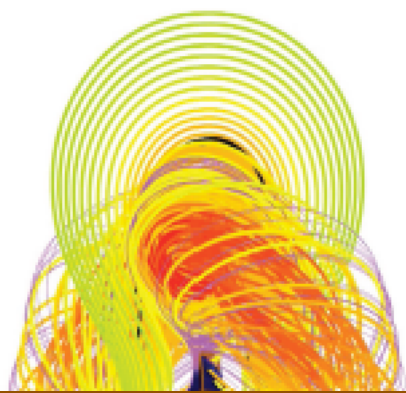
CMS model

van Ballegooijen, Savcheva

Parameters: axial and poloidal flux

13 X 13 grid



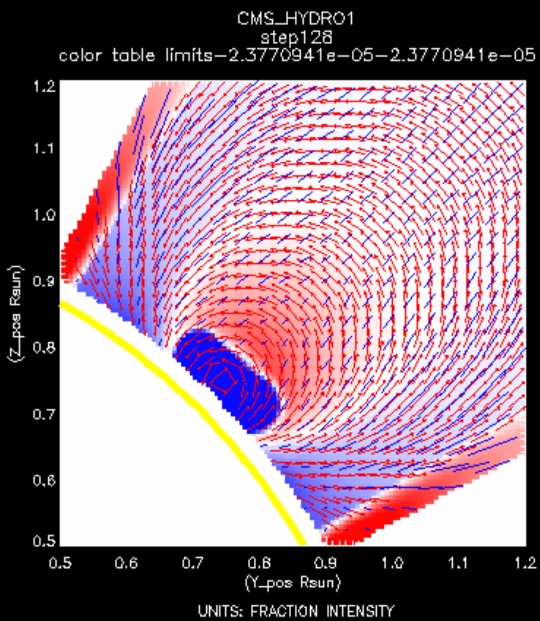


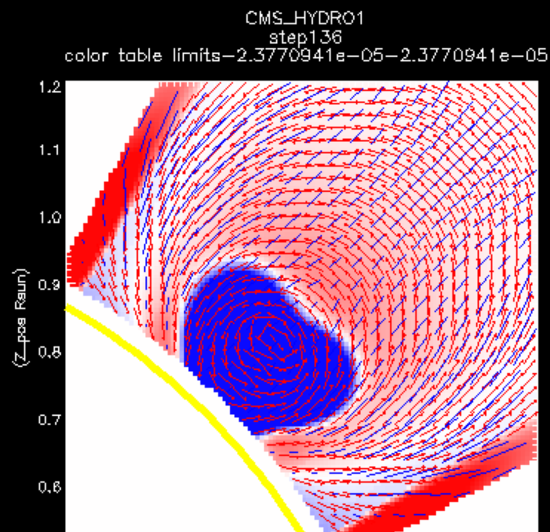
Fan simulation

Applying ROAM

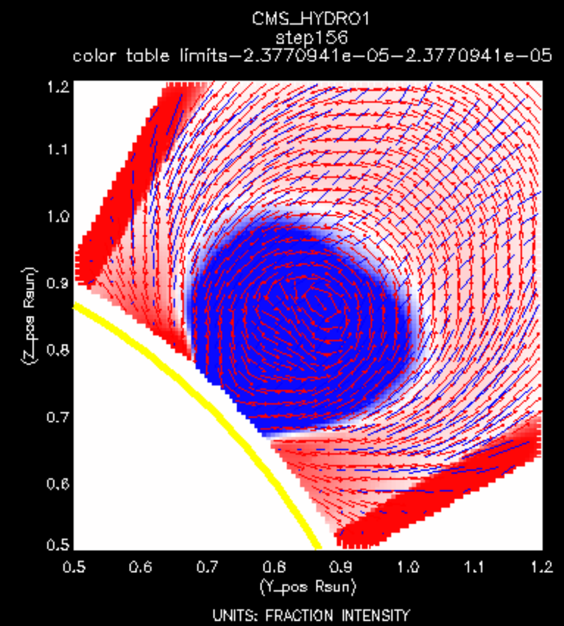
V/I

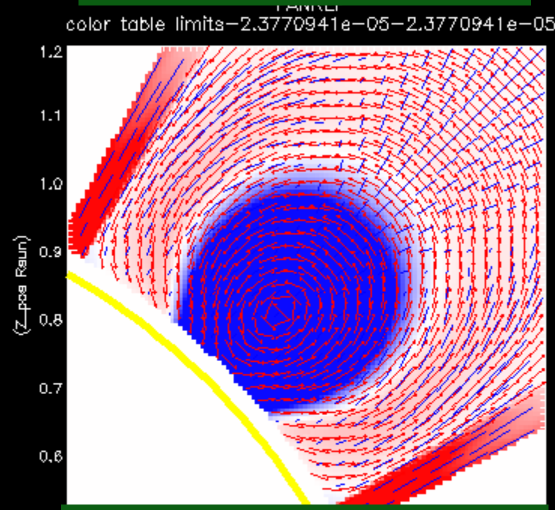
Dalmasse et al., in preparation





CMS models





Fan simulation

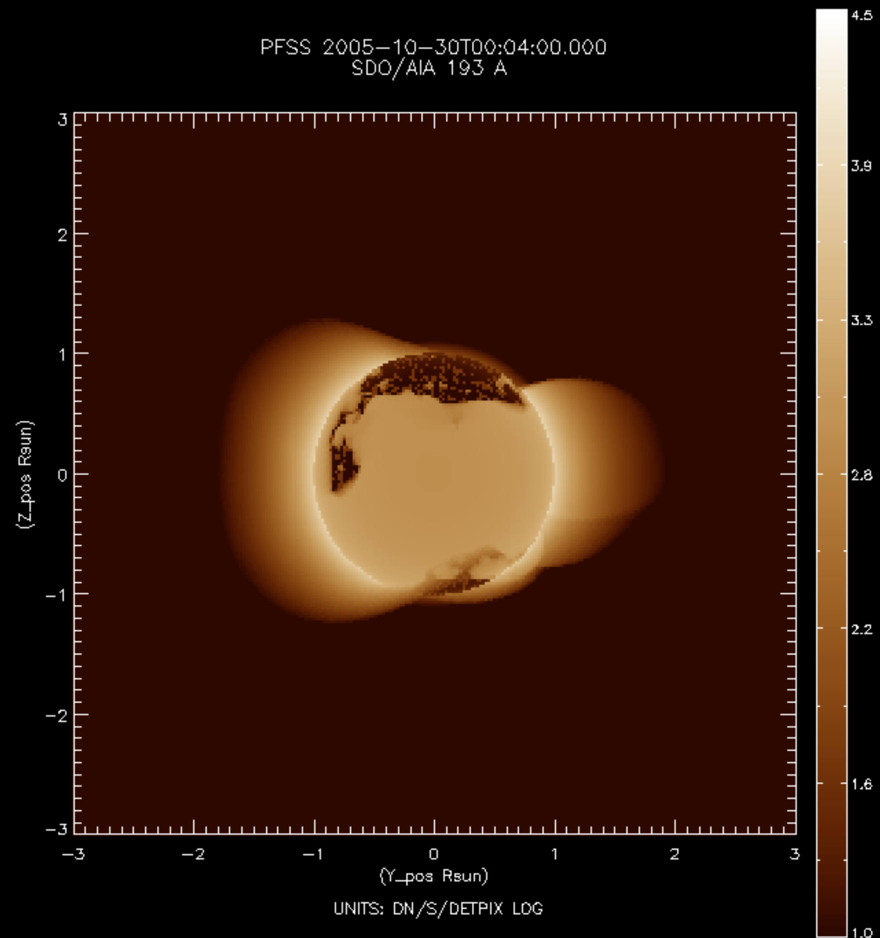
Applying ROAM

Dalmasse et al., in preparation

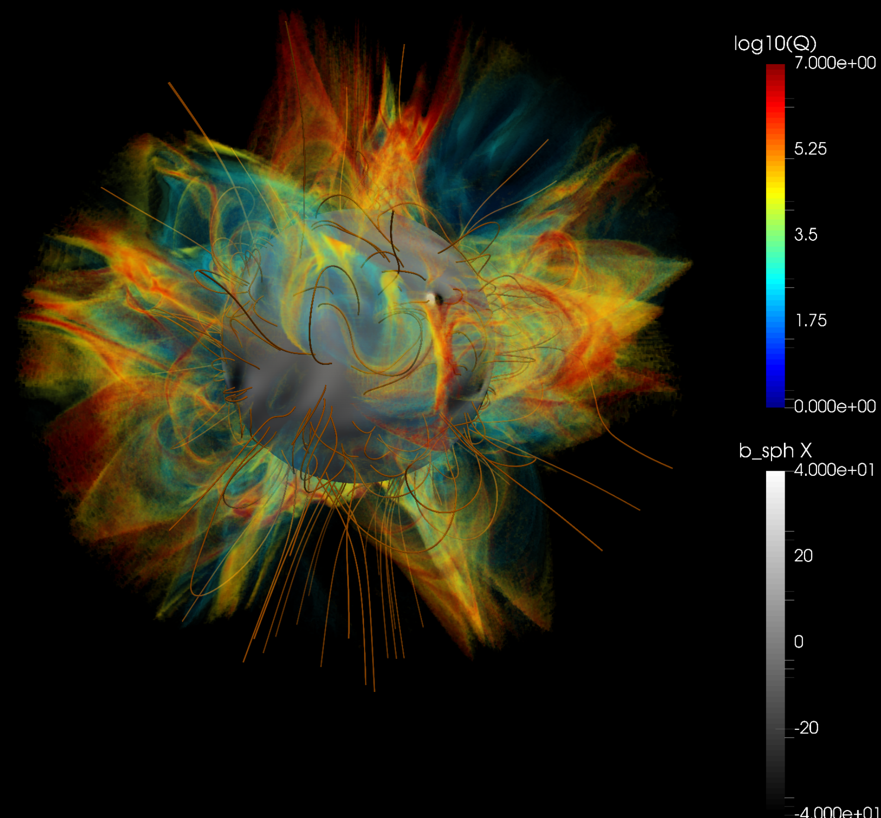
Initial results:
Axial flux better constrained than poloidal by polarimetric data

CMS requires density model:
- hydrostatic
- current-dependent
- “true” density

Density weighting: Global



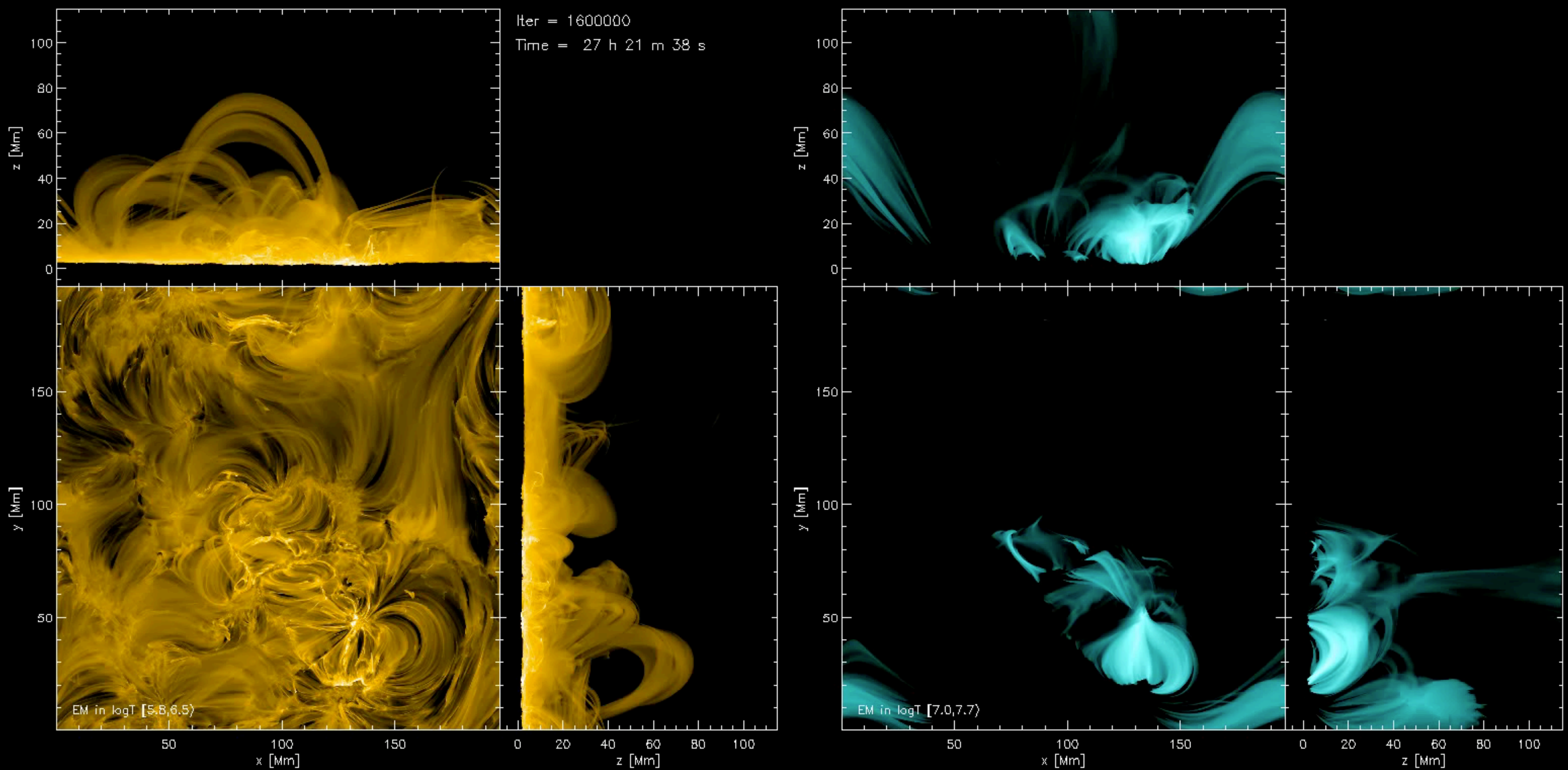
Working to apply it to Mackay global models



New capability in FORWARD: open vs. closed topology density weighting

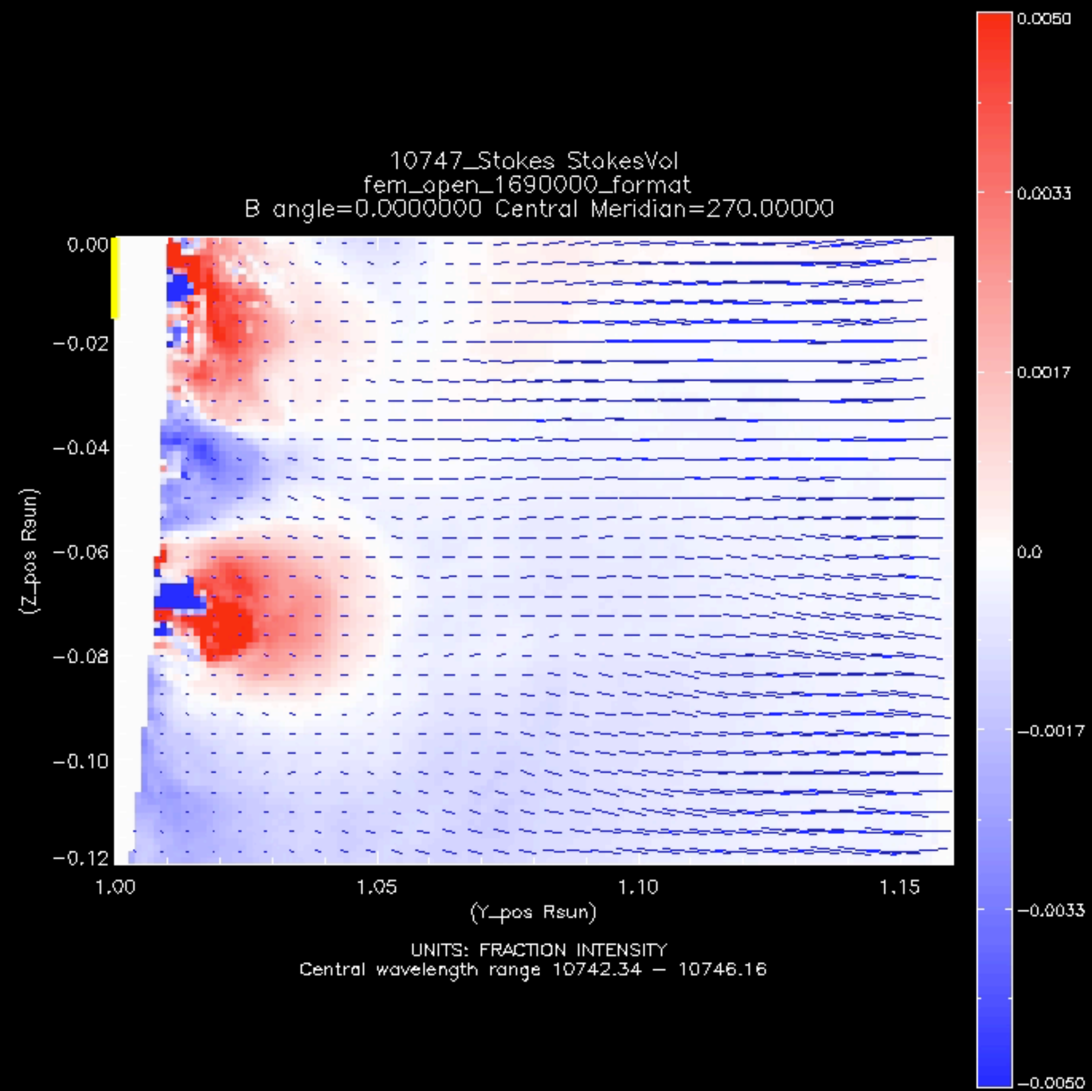
Tassev

Complex test bed: CME, flares



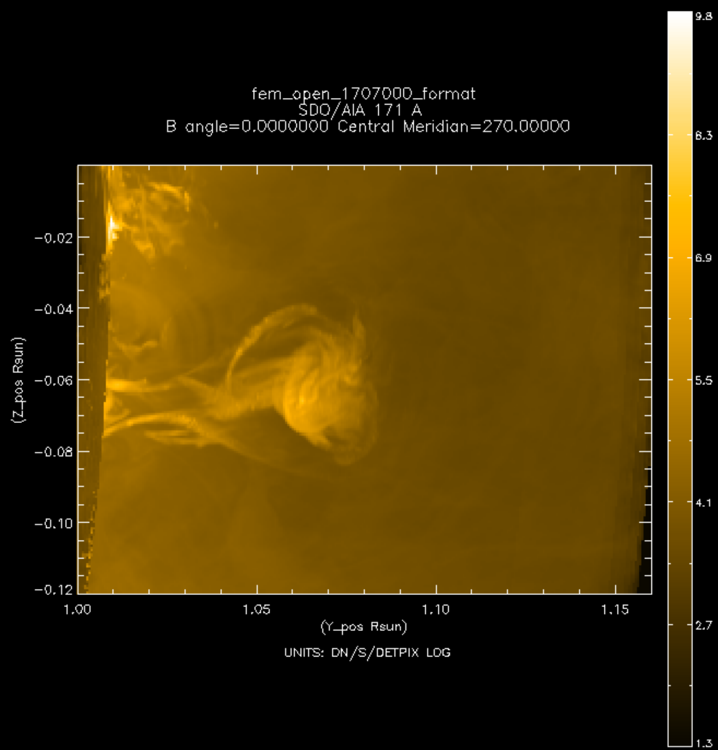
Rempel; Chen et al., 2017

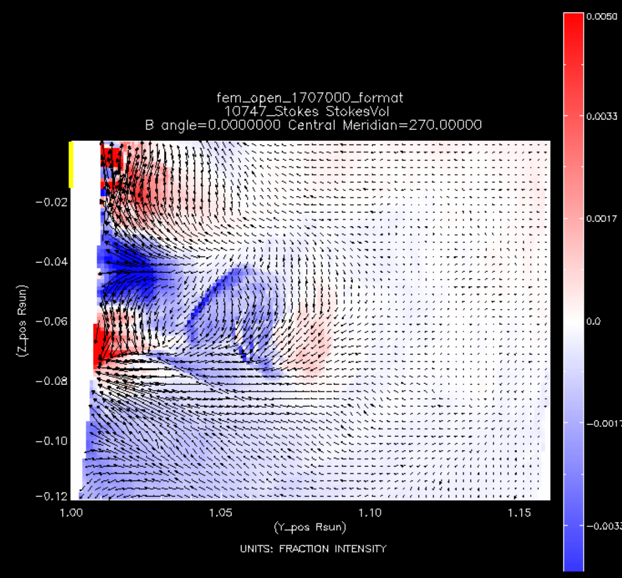
Sensitivity to polarimetric data

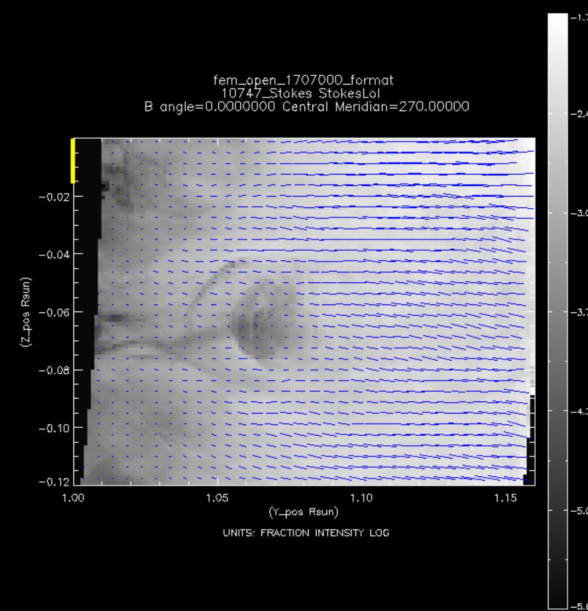


Kenzie Nimmo; REU summer project

Sensitivity to polarimetric data





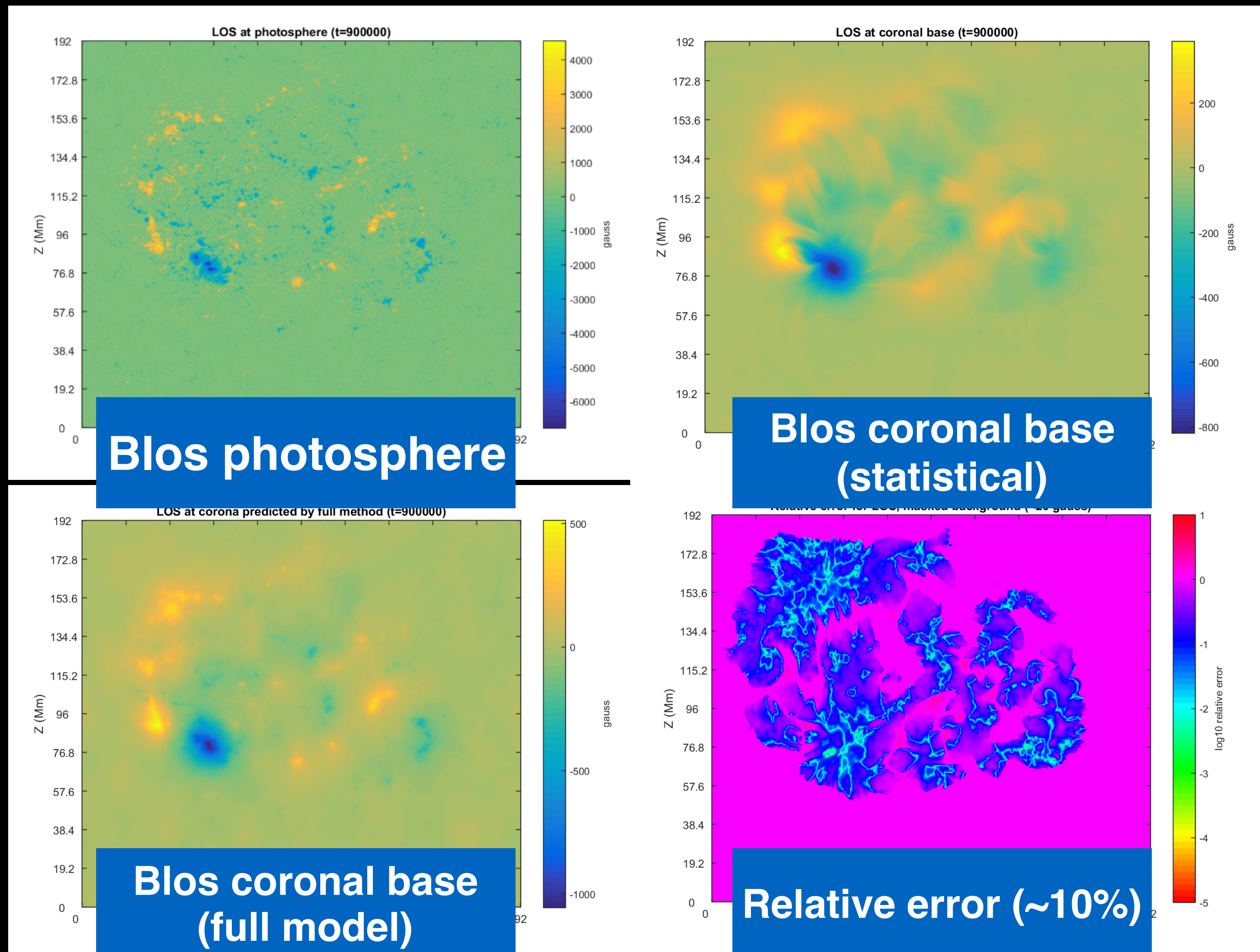


Exposes sensitivities of polarimetric data to high densities, temperatures, and velocities

Kenzie Nimmo; REU summer project

Coronal base boundary condition

Machine learning — statistical regression model



Nathaniel Mathews - CU graduate student

How to use this new polarimetric diagnostic

Identify **how/where measurements are sensitive** to coronal magnetic fields:

- cavities — linear-polarization lagomorphs
  - expect clear signature in circular polarization (DKIST, COSMO…)
- pseudostreamers — linear-polarization lobes and nulls
- streamer/coronal hole interface — non-radial expansion in azimuth

How to use this new polarimetric diagnostic

Establish **quantitative indices** of that sensitivity:

- non-potentiality index from cavity circular polarization - tracks free energy
  - how do we use the information in the linear polarization lagomorphs?
- magnetic null heights from linear polarization in pseudostreamers
- non-radial expansion from azimuth at streamer/coronal hole interface

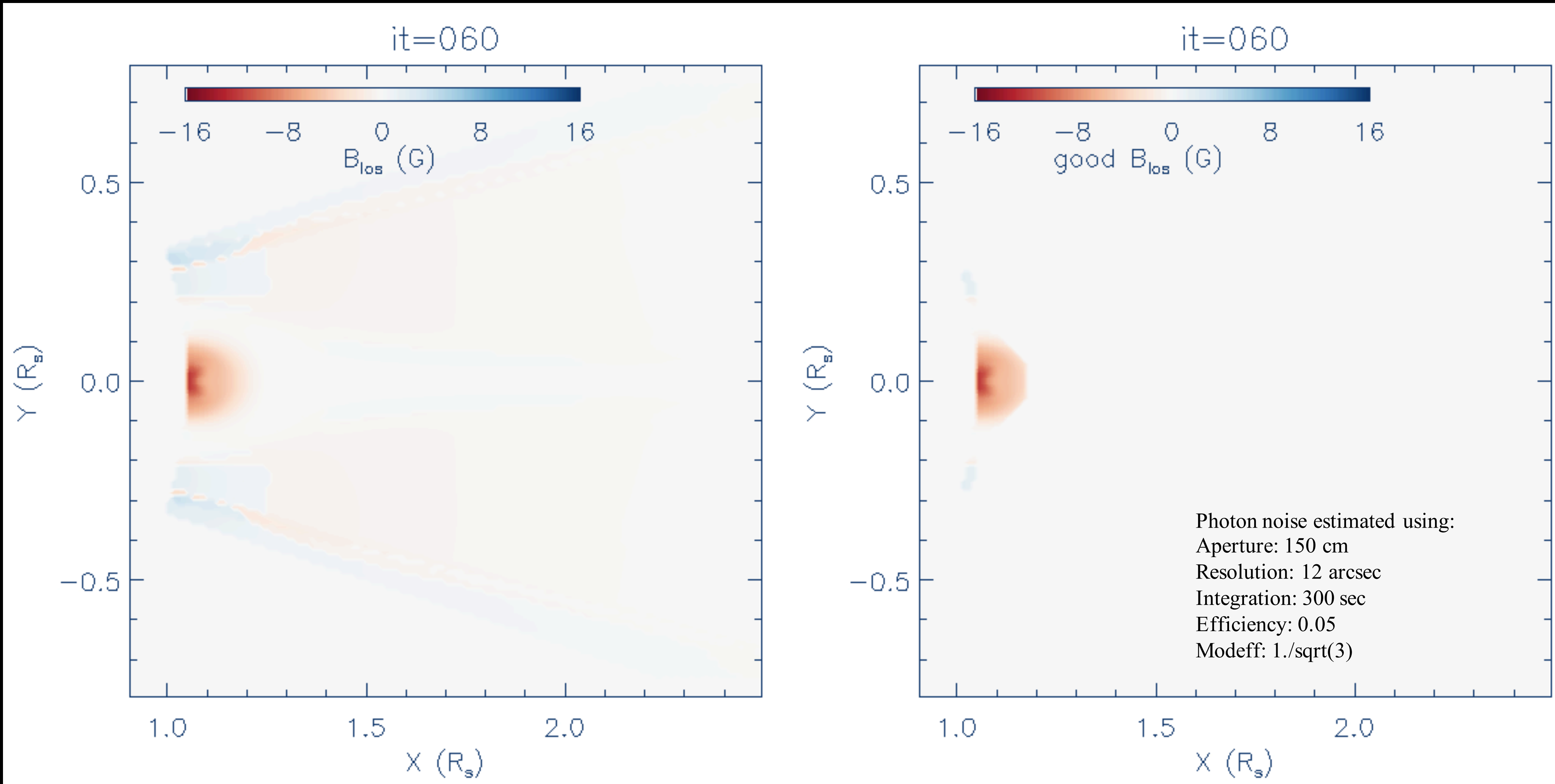
How to use this new polarimetric diagnostic

Use these indices to help **optimize coronal magnetic models**

- Finish flux-rope fit to Fan simulation (*Dalmasse et al.)*
  - Iterative ROAM
  - Test robustness to density model
  - Consider other contributions to loss function (magnetic skeleton — *Malanushenko)*

- Create optimized model of pseudostreamer (4/15/2015) (*Karna et al.*)
  - Incorporate height of null, polarization expansion factor in loss function

- Sensitivities to noise, measurement uncertainties (*Fan et al.*)



it=060
-16 -8 0 8 16
B_los (G)
0.5
0.0
-0.5
Y (R_s)
1.0 1.5 2.0
X (R_s)
it=060
-16 -8 0 8 16
good B_los (G)
0.5
0.0
-0.5
Y (R_s)
1.0 1.5 2.0
X (R_s)
Photon noise estimated using:
Aperture: 150 cm
Resolution: 12 arcsec
Integration: 300 sec
Efficiency: 0.05
Modeff: 1./sqrt(3)

How to use this new polarimetric diagnostic

Test **robustness** of polarization sensitivities with respect to different models:

- correlation of polarimetric data to free energy (*Corchado Albelo et al.)*
- sensitivities to density, temperature, velocity (*Nimmo et al.*)
- develop generalized solver (*Mathew et al.*)

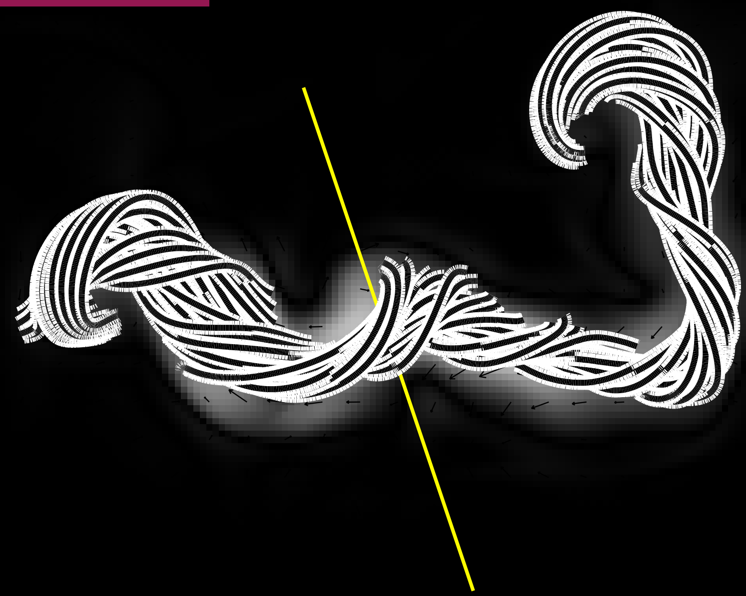
How to use this new polarimetric diagnostic

Determine usefulness of non-potentiality index for **prediction** using **observations:**

- **CoMP observations of erupting vs. non-erupting cavities**
- **Calculate non-potentiality index; analyze trends**

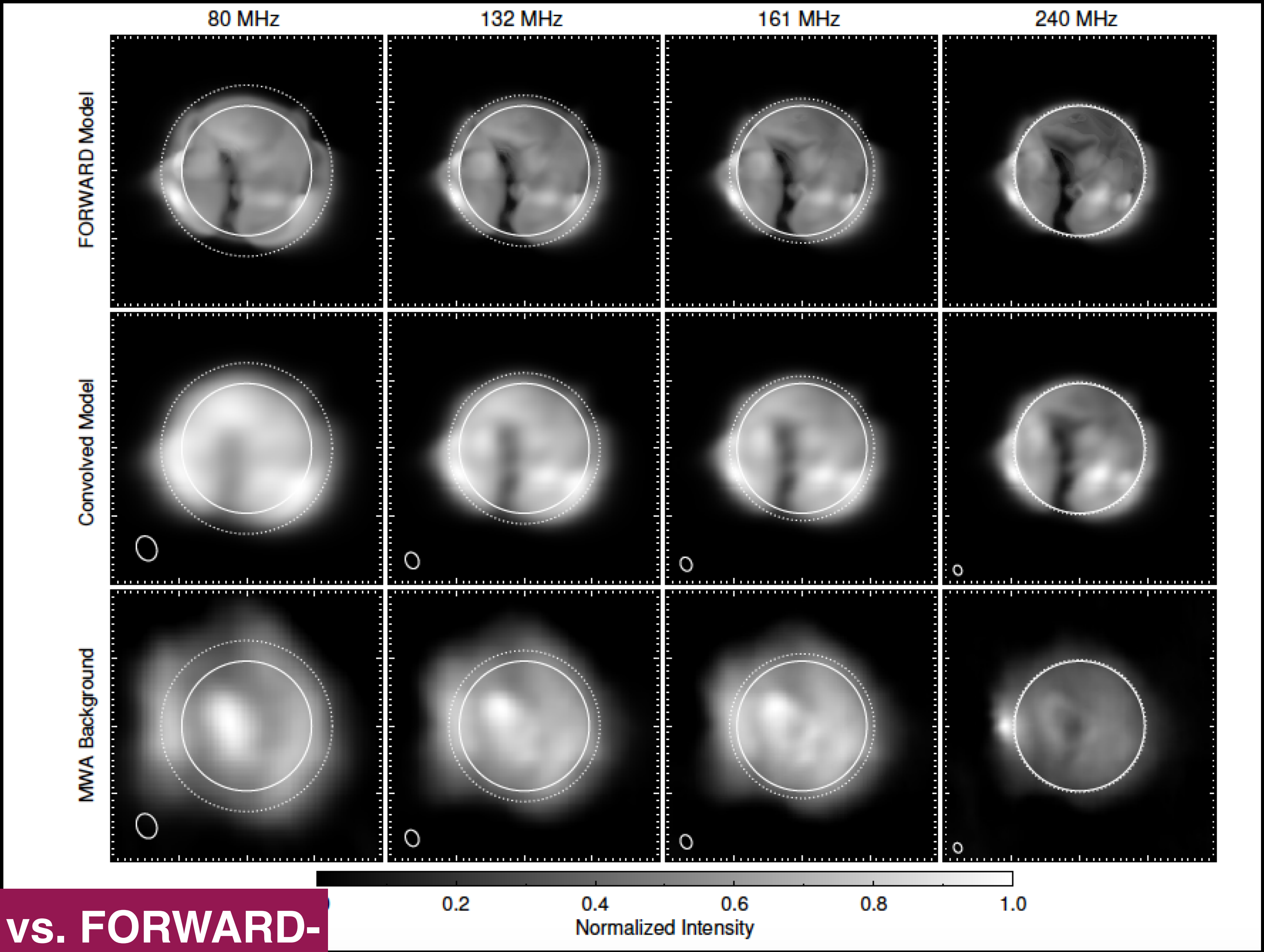
Connections to other teams

Bastille-day event flux rope insertion - collaboration with PSI



Savcheva et al., in preparation

Connections to other teams



MWA vs. FORWARD-modeled MAS

McCauley et al. submitted