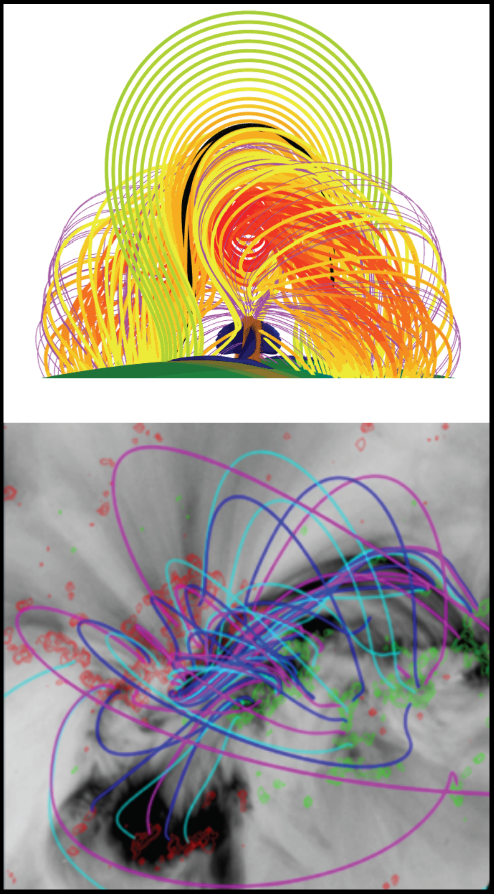
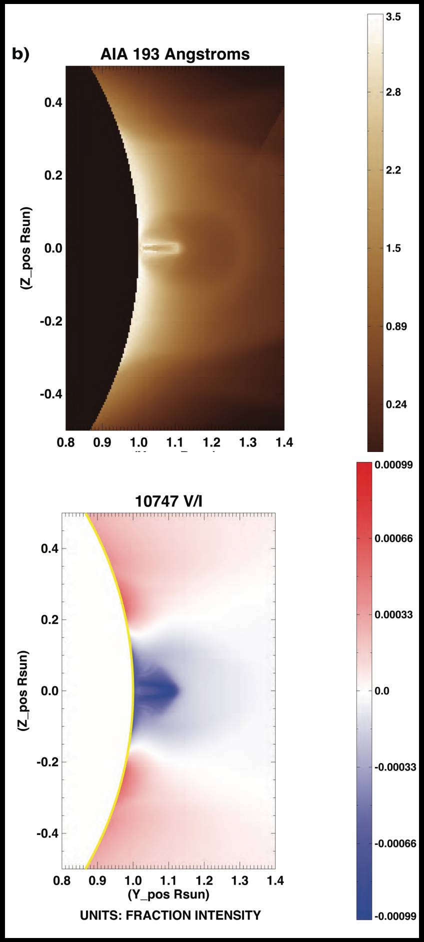
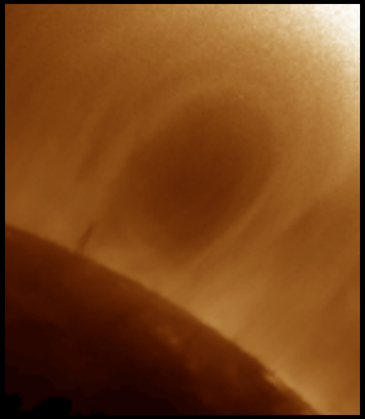
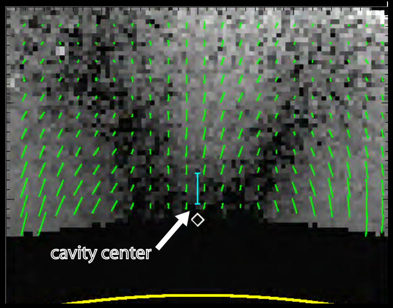
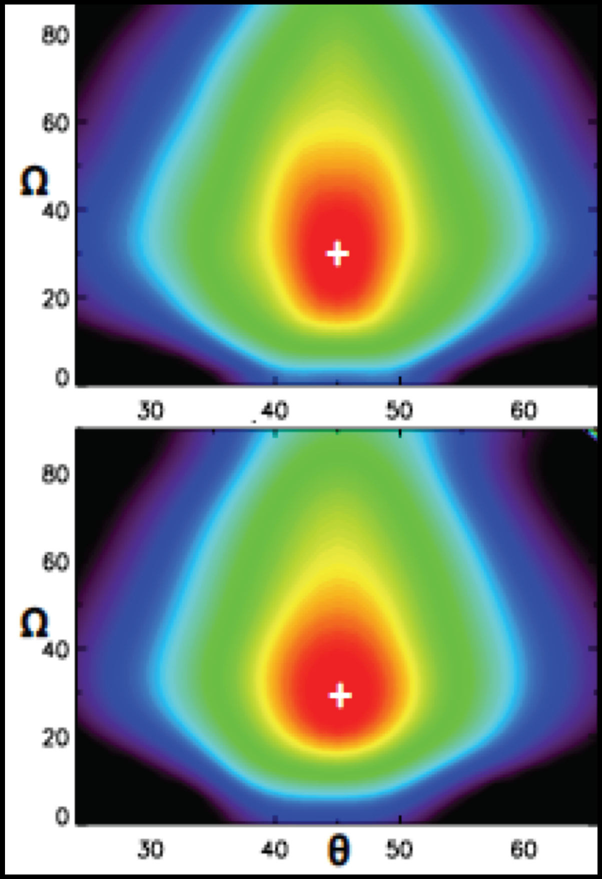
Towards a Data-Optimized Coronal Magnetic Field Model (DOC-FM):





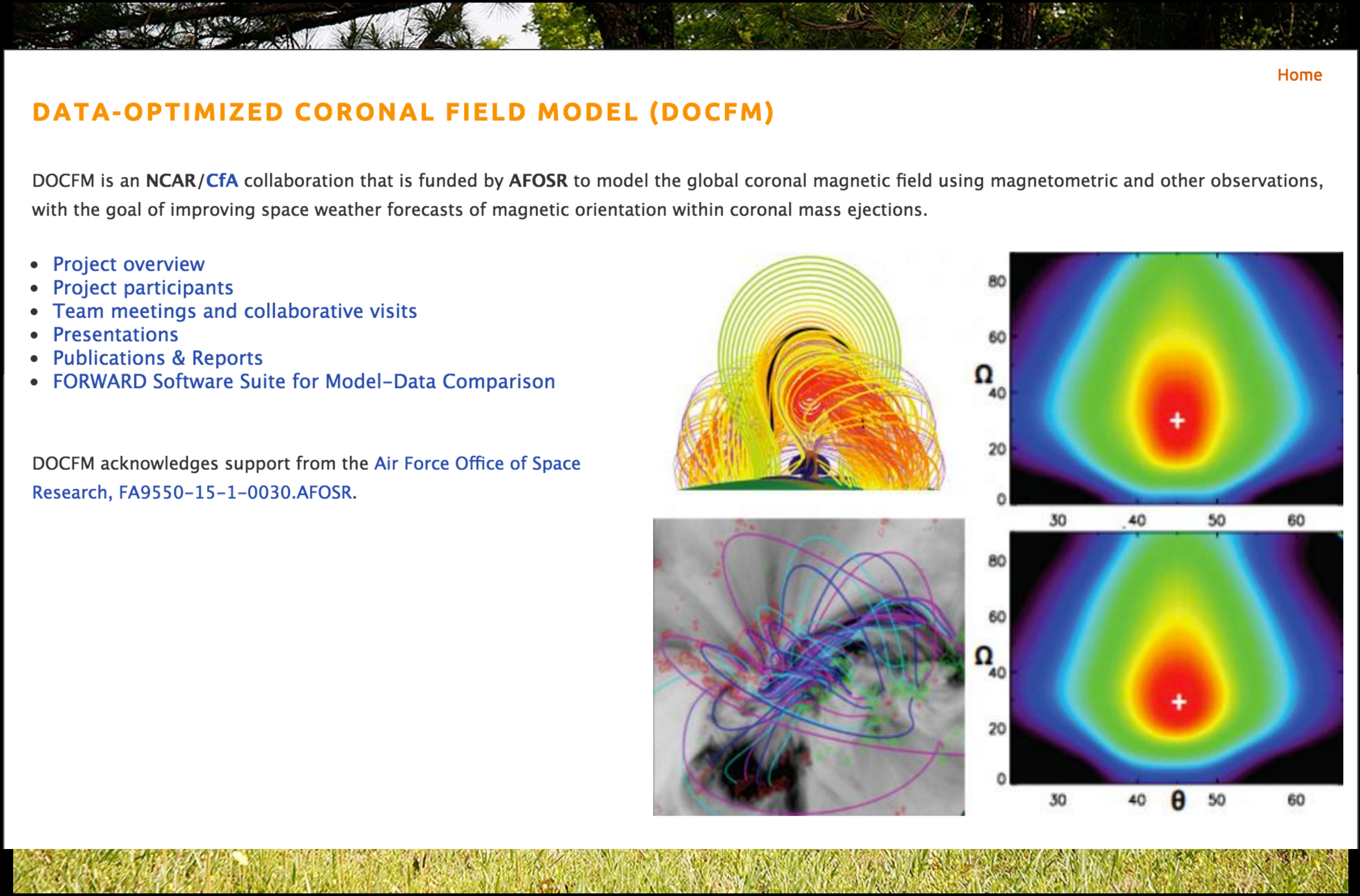






Sarah E Gibson, Ed Deluca, Kévin Dalmasse, Giuliana de Toma, Yuhong Fan, Duncan Mackay, Karen Meyer, Patricia Jibben, Jenna Samra, Antonia Savcheva, Steve Tomczyk Doug Nychka, Silvano Fineschi, Natasha Flyer, Anna Malanushenko, Nathaniel Mathews

www.hao.ucar.edu/DOCFM/



Home

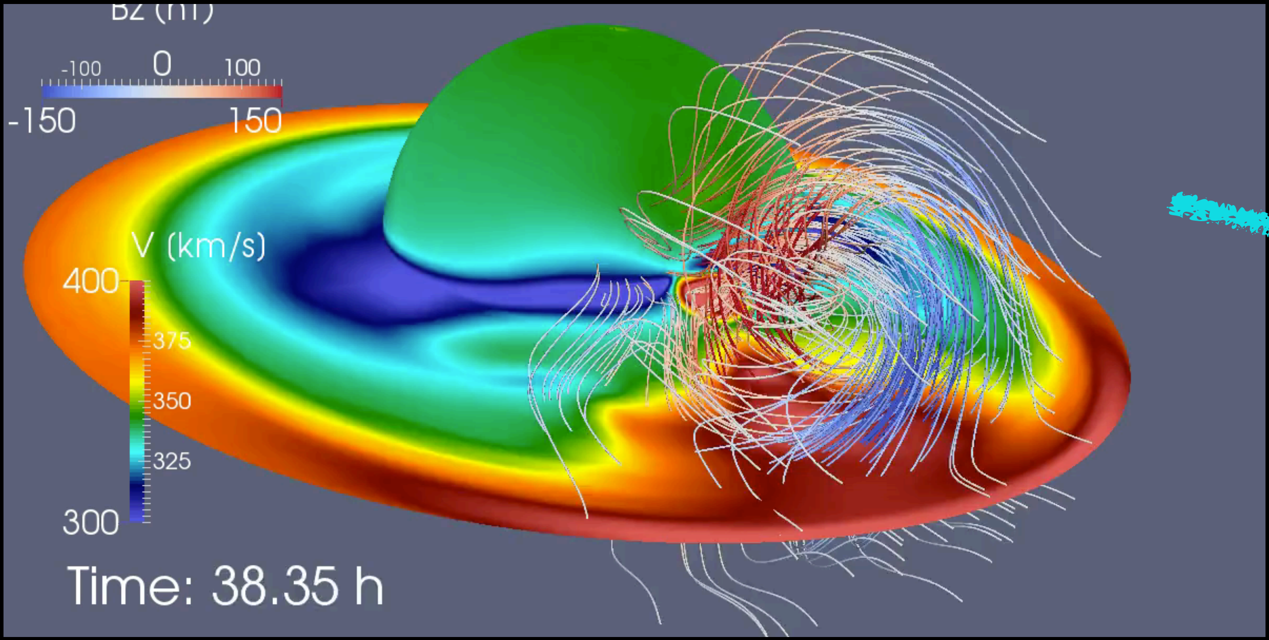
DATA-OPTIMIZED CORONAL FIELD MODEL (DOCFM)

DOCFM is an **NCAR**/CfA collaboration that is funded by **AFOSR** to model the global coronal magnetic field using magnetometric and other observations, with the goal of improving space weather forecasts of magnetic orientation within coronal mass ejections.

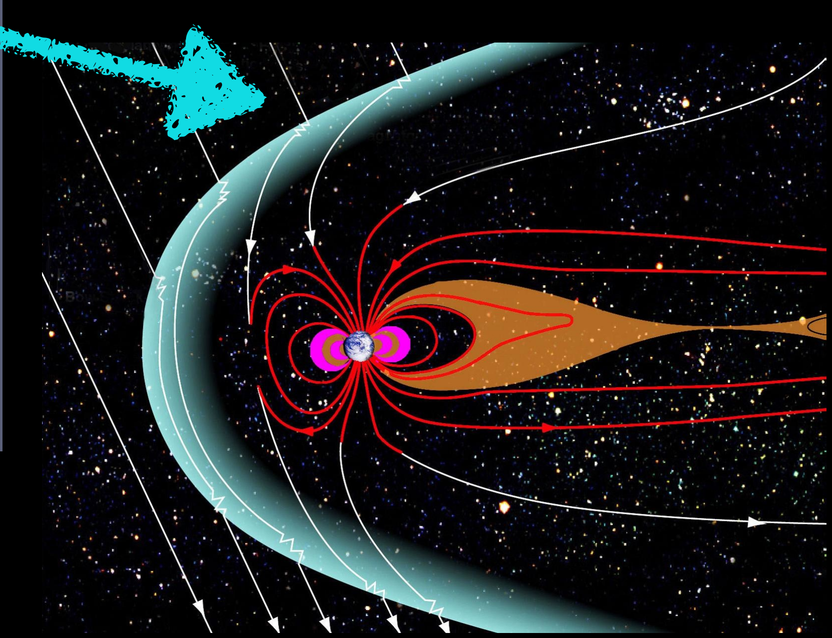
- Project overview
- Project participants
- Team meetings and collaborative visits
- Presentations
- Publications & Reports
- FORWARD Software Suite for Model–Data Comparison

DOCFM acknowledges support from the Air Force Office of Space Research, FA9550-15-1-0030.AFOSR.

Why do we need coronal magnetometry?



Courtesy Merkin, Lyon, Wiltberger



If we ever want to predict Bz at the Earth, we need to be able to quantify the *global* coronal magnetic field

Begin at the end
(what we ultimately want to be able to do)

Automatic daily, global, 3D coronal magnetic maps - including all currents

LOS photospheric field snapshot does not contain sufficient information

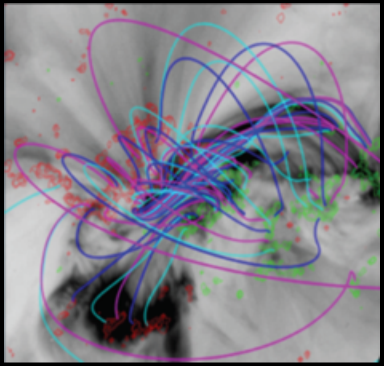
- vector magnetic fields
- time-varying boundary
- **add currents parametrically**

- Start from nearby solution (MHD model, “yesterday’s prediction”)
- Use photospheric boundary condition <u>and</u> coronal data
- Use synthetic testbeds to develop method:
    - gives “ground truth” for assessing performance
    - lets us determine sensitivity to various coronal observables

Data-optimized coronal field model (DOC-FM)

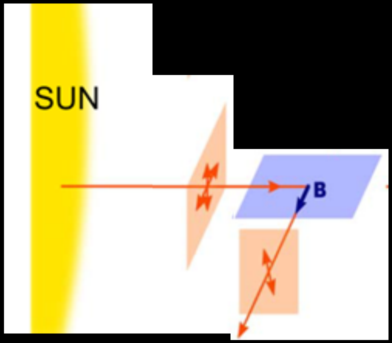
MHD-model based approach to forward-fitting the global field (NCAR-CfA collaboration)

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

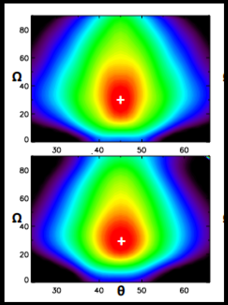


Maximize posterior

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

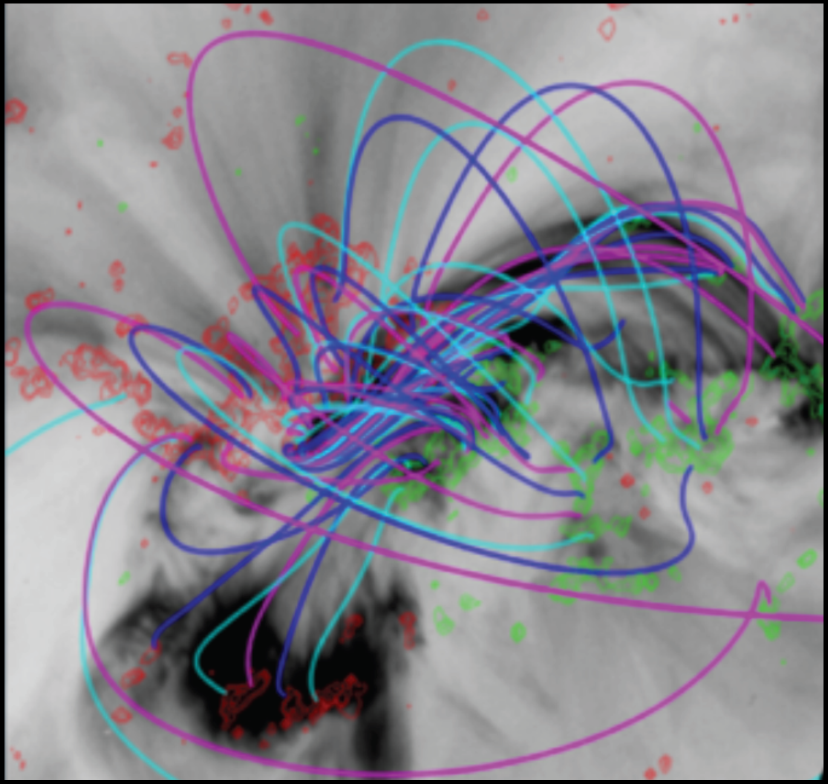


Calculation of likelihood comparing synthetic vs. measured *observations* – efficient statistical methods



Modify model

Parameterized model



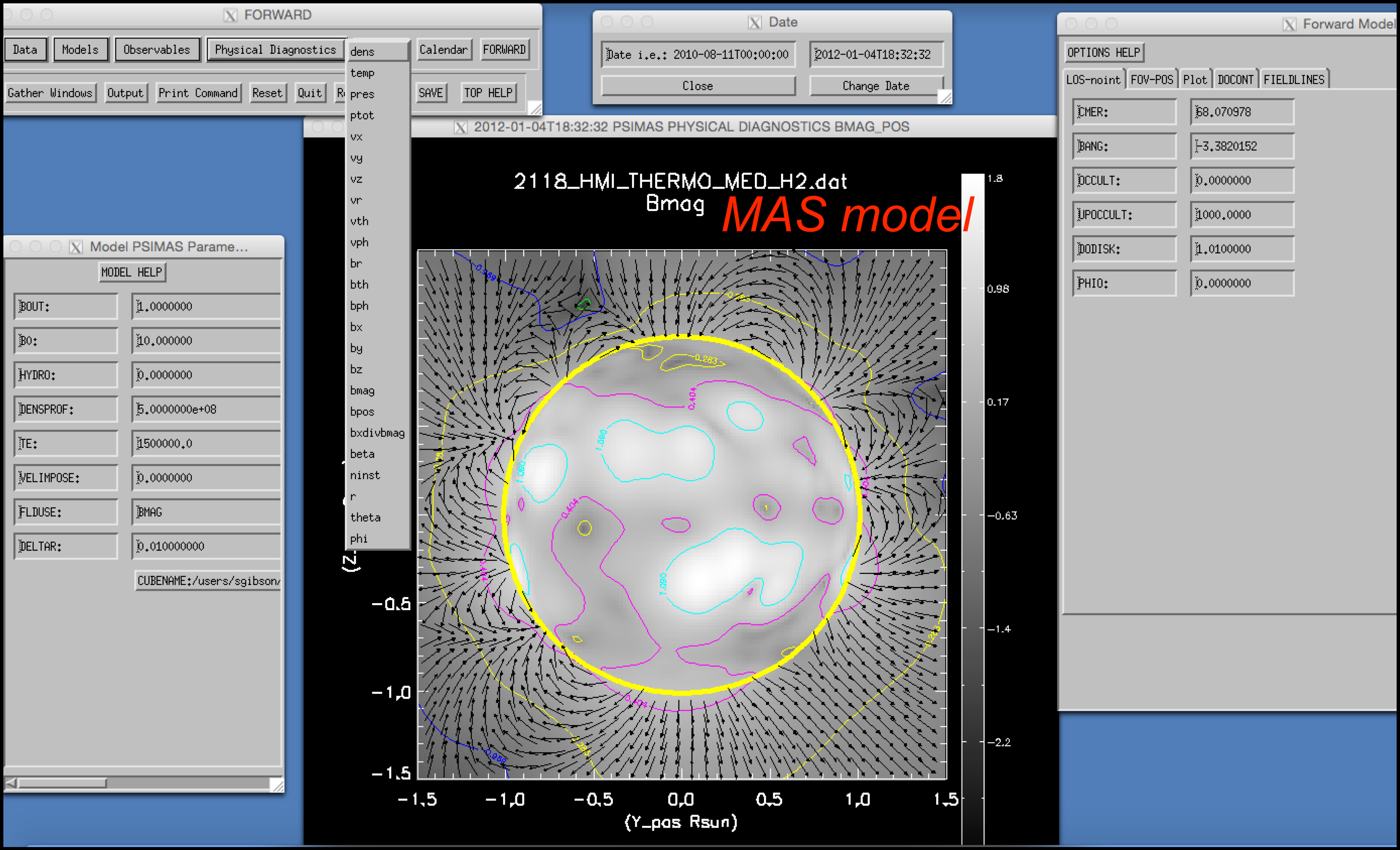
Savcheva and van Ballegooijen, 2009

Flux-rope insertion method. Uses e.g. path of filament to define volume within initial potential field extrapolation where flux rope is inserted. Axial and poloidal flux of the embedded are free parameters.

Uses magneto frictional method to relax to force-free equilibrium where flux rope is confined by surrounding fields.

Can be embedded in a global model.

FORWARD: Physical state



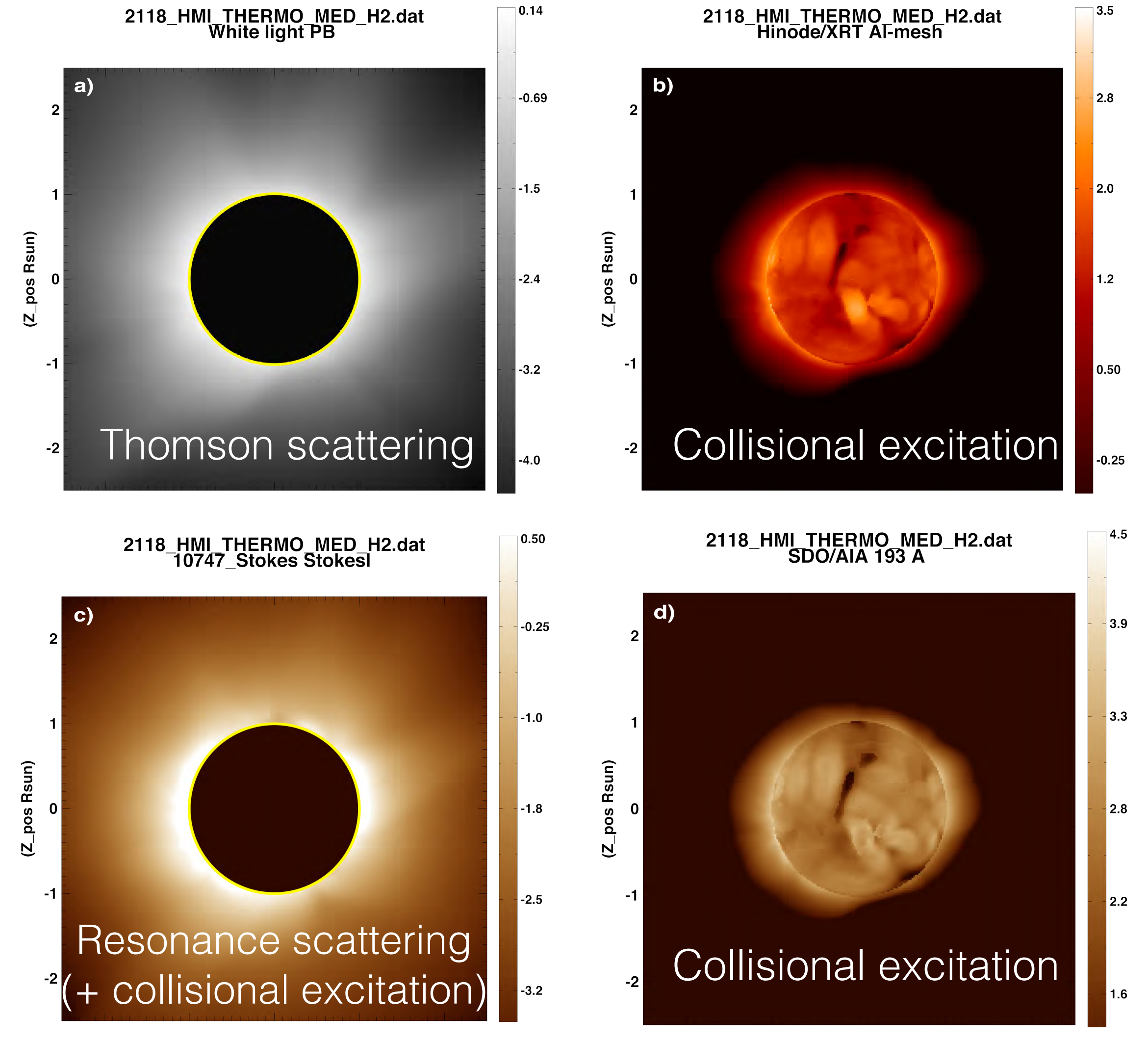
Date i.e.: 2010-08-11T00:00:00
2012-01-04T18:32:32

BOUT: 1.0000000
B0: 10.000000
HYDRO: 0.0000000
DENSPROF: 5.0000000e+08
TE: 1500000.0
VELIMPOSE: 0.0000000
FLDUSE: BMAG
DELTAR: 0.010000000
CUBENAME:/users/sgibson/

CMER: 68.070978
BANG: -3.3820152
OCCULT: 0.0000000
UPOCCULT: 1000.0000
DODISK: 1.0100000
PHIO: 0.0000000

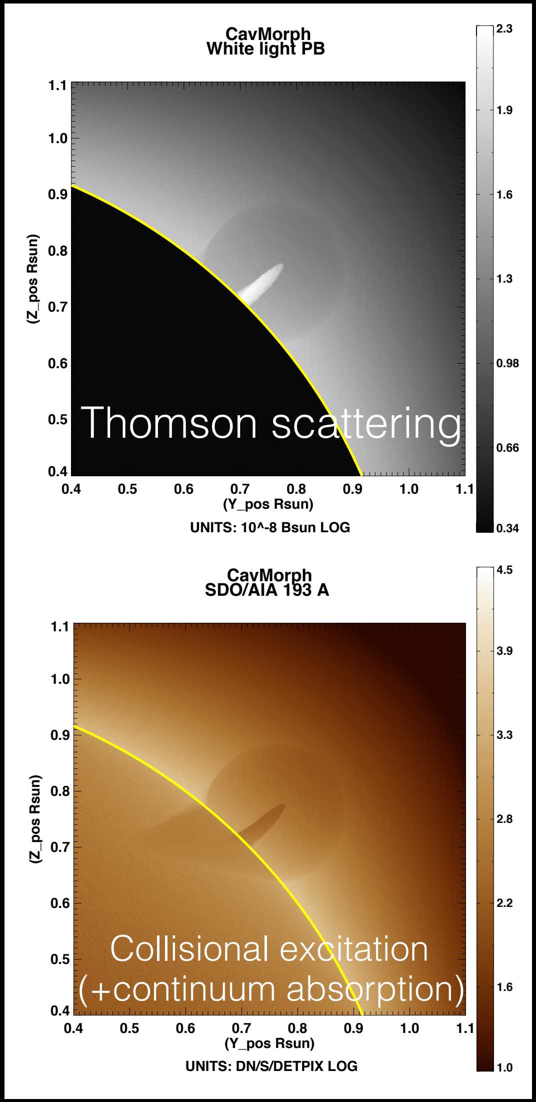
- analytic, numerical (user-inputted), or web-accessed (PFSS, MAS)

FORWARD: Physical processes

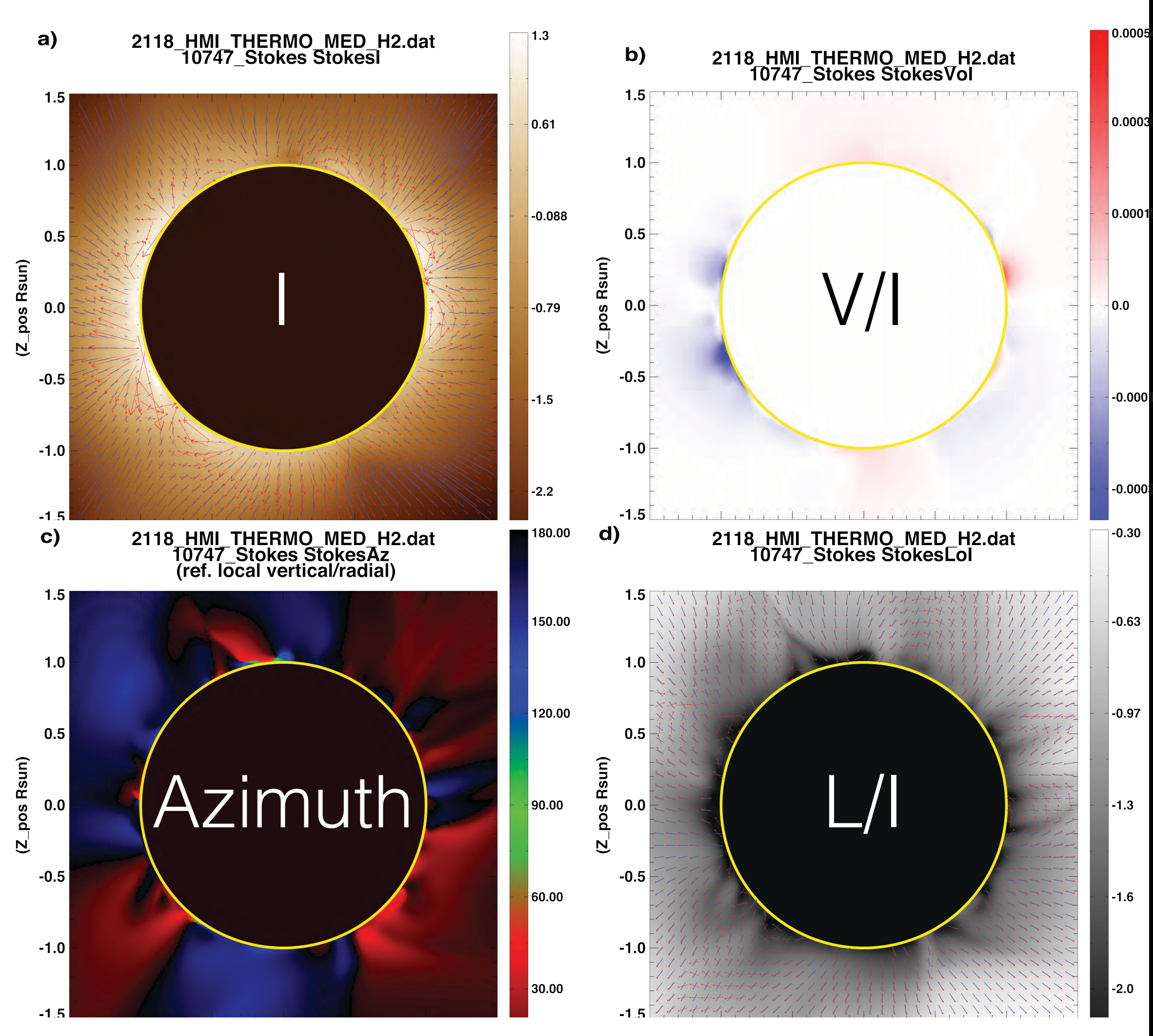


MAS model

CAVMORPH model



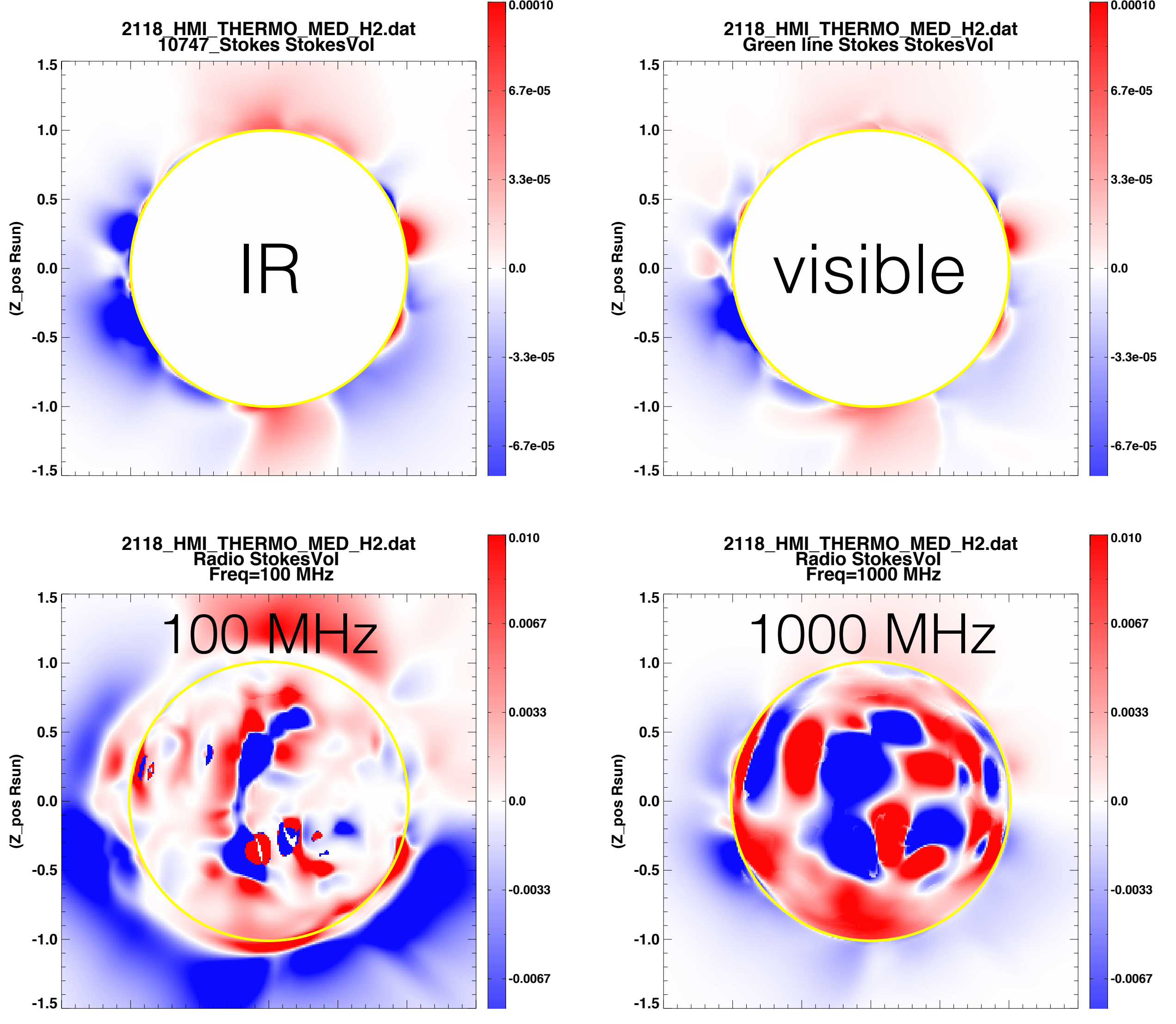
FORWARD: Physical processes



MAS model

Polarization (Zeeman, saturated Hanle)

FORWARD: Physical processes

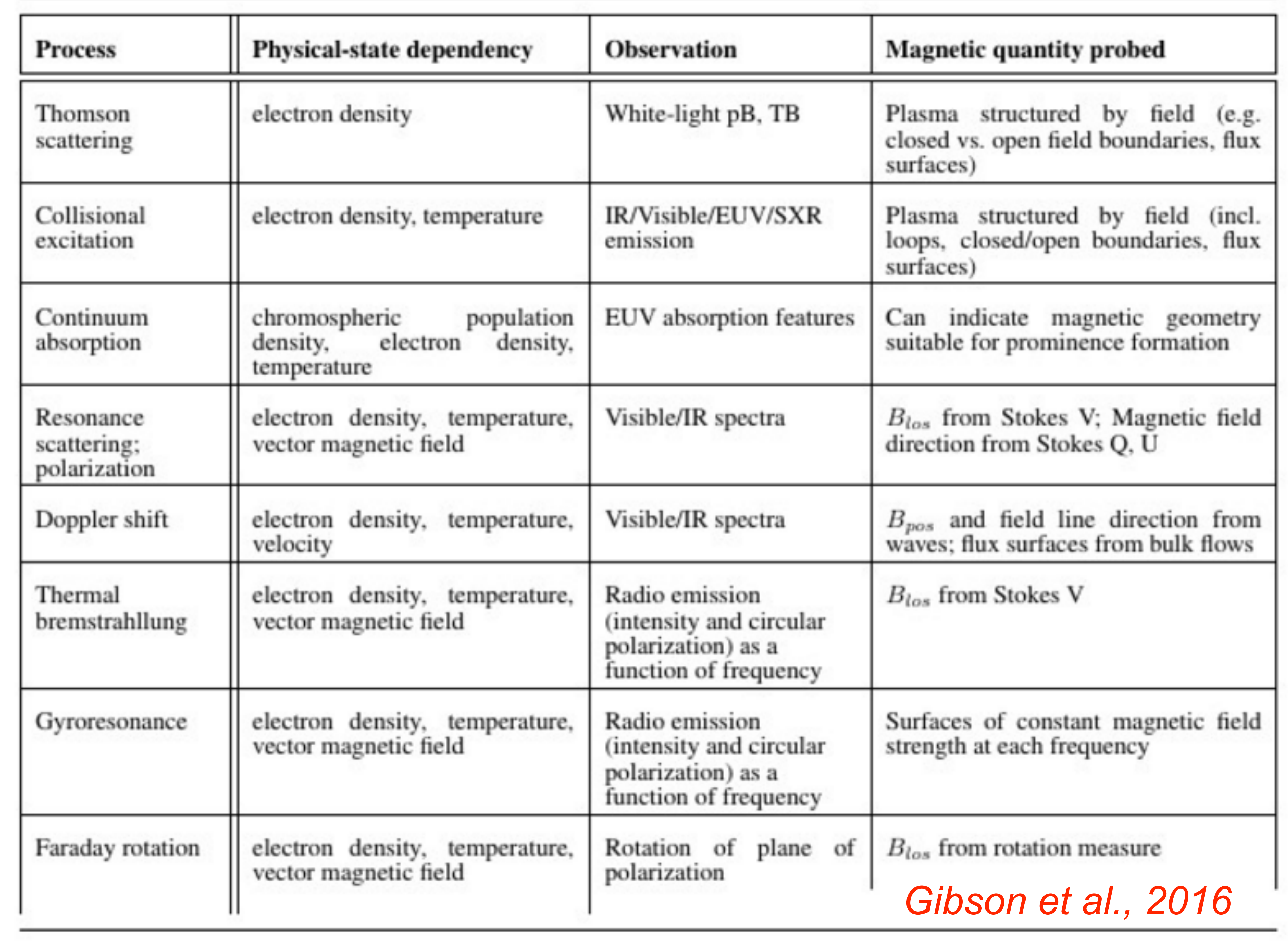


MAS model

Circular polarization at different wavelengths:

different dependencies on plasma along the line of sight

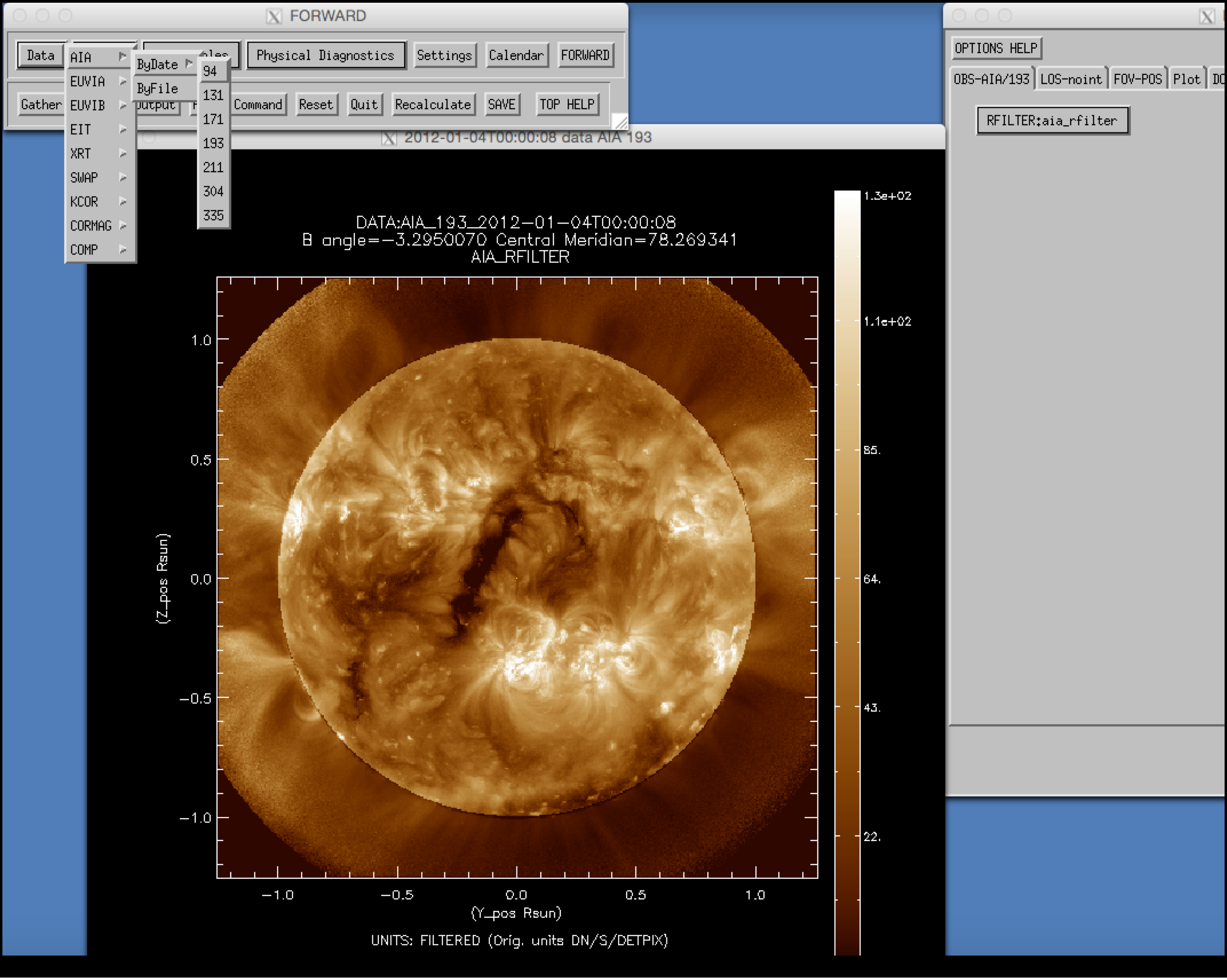
FORWARD: Physical processes



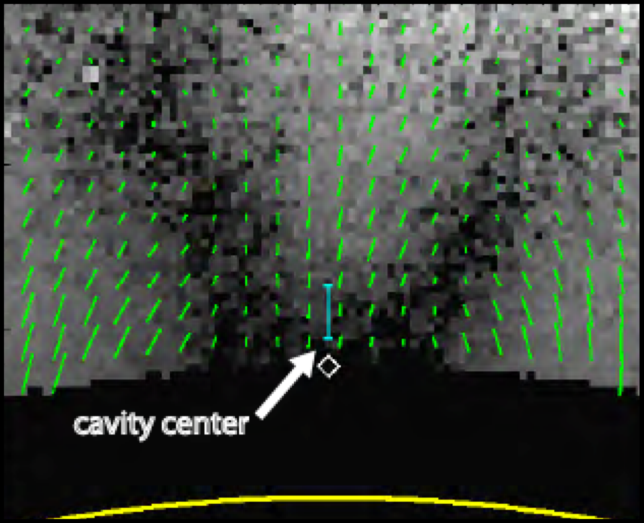
Process	Physical-state dependency	Observation	Magnetic quantity probed
Thomson scattering	electron density	White-light pB, TB	Plasma structured by field (e.g. closed vs. open field boundaries, flux surfaces)
Collisional excitation	electron density, temperature	IR/Visible/EUV/SXR emission	Plasma structured by field (incl. loops, closed/open boundaries, flux surfaces)
Continuum absorption	chromospheric population density, electron density, temperature	EUV absorption features	Can indicate magnetic geometry suitable for prominence formation
Resonance scattering; polarization	electron density, temperature, vector magnetic field	Visible/IR spectra	B_{los} from Stokes V; Magnetic field direction from Stokes Q, U
Doppler shift	electron density, temperature, velocity	Visible/IR spectra	B_{pos} and field line direction from waves; flux surfaces from bulk flows
Thermal bremstrahllung	electron density, temperature, vector magnetic field	Radio emission (intensity and circular polarization) as a function of frequency	B_{los} from Stokes V
Gyroresonance	electron density, temperature, vector magnetic field	Radio emission (intensity and circular polarization) as a function of frequency	Surfaces of constant magnetic field strength at each frequency
Faraday rotation	electron density, temperature, vector magnetic field	Rotation of plane of polarization	B_{los} from rotation measure

Gibson et al., 2016

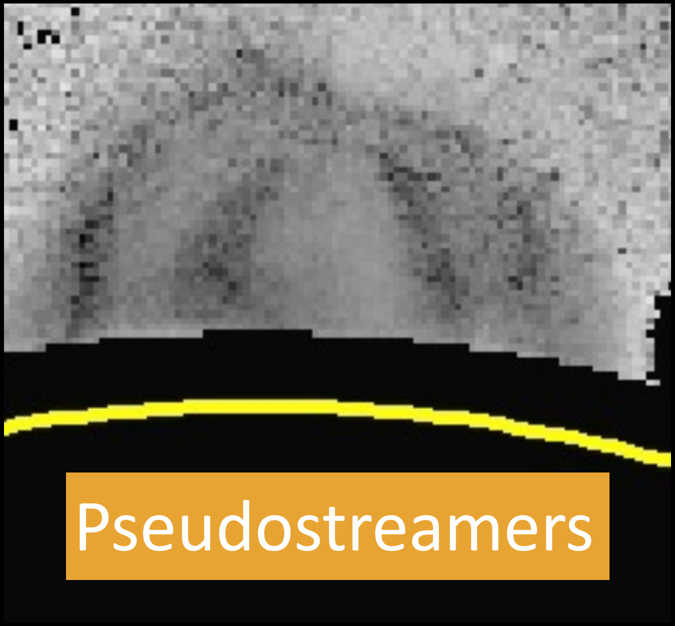
FORWARD: Observations via VSO



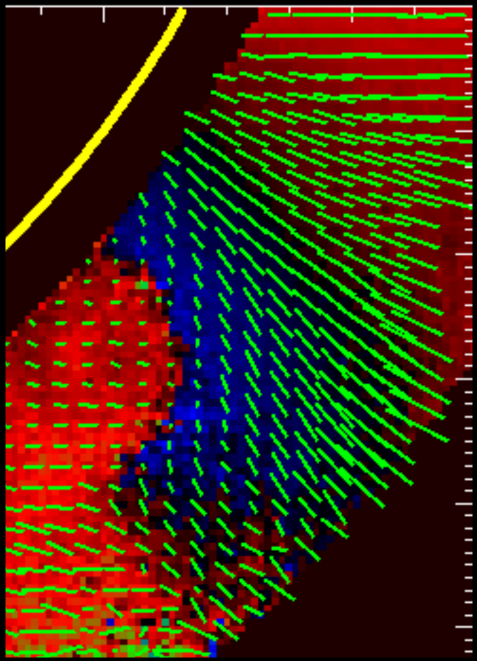
FORWARD: CoMP Observations



Lagomorphs



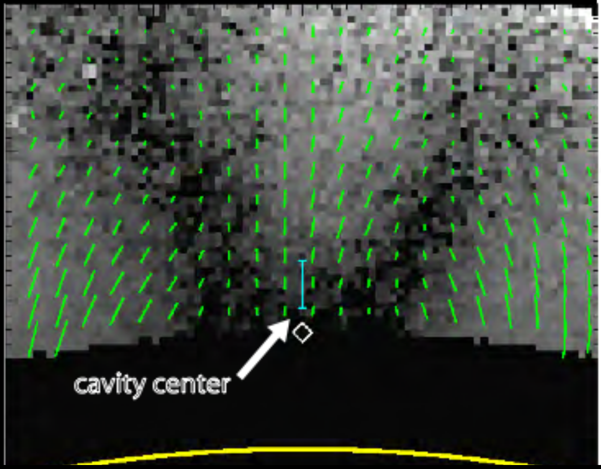
Pseudostreamers

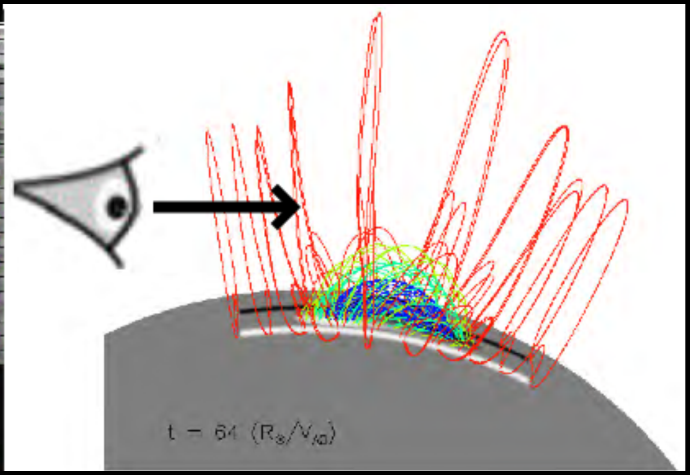


Non-radial expansion

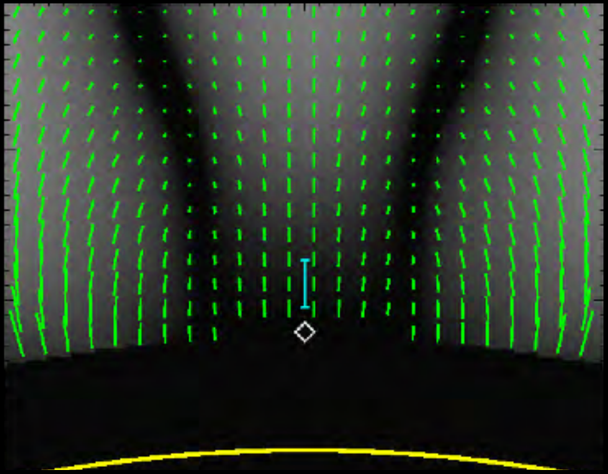
Lagomorphs, cavities and flux ropes

DATA

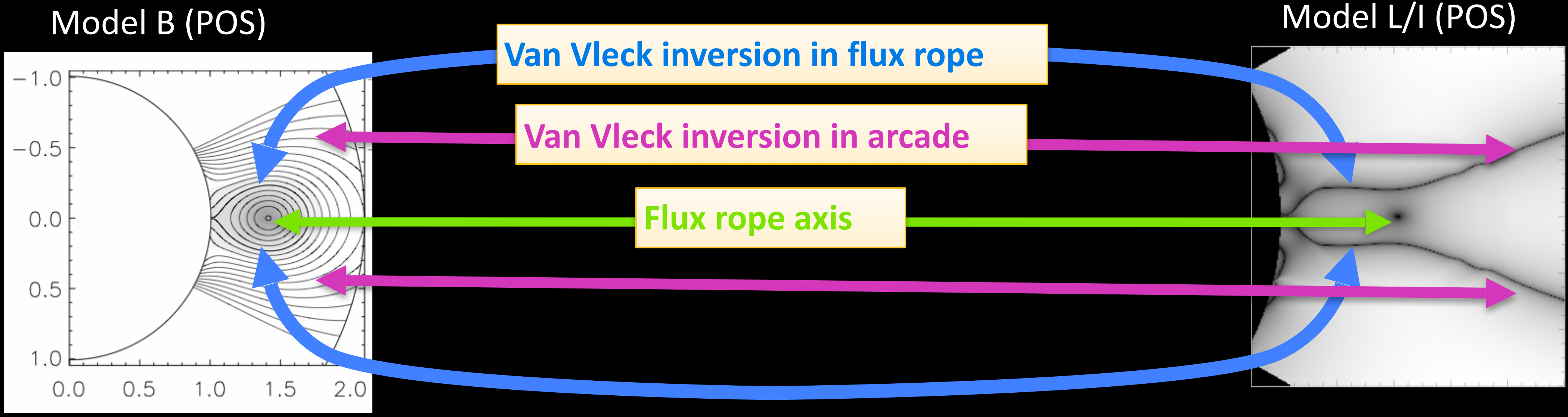




MODEL



Diagnostic of magnetic flux rope


Model B (POS)

Model L/I (POS)

Van Vleck inversion in flux rope

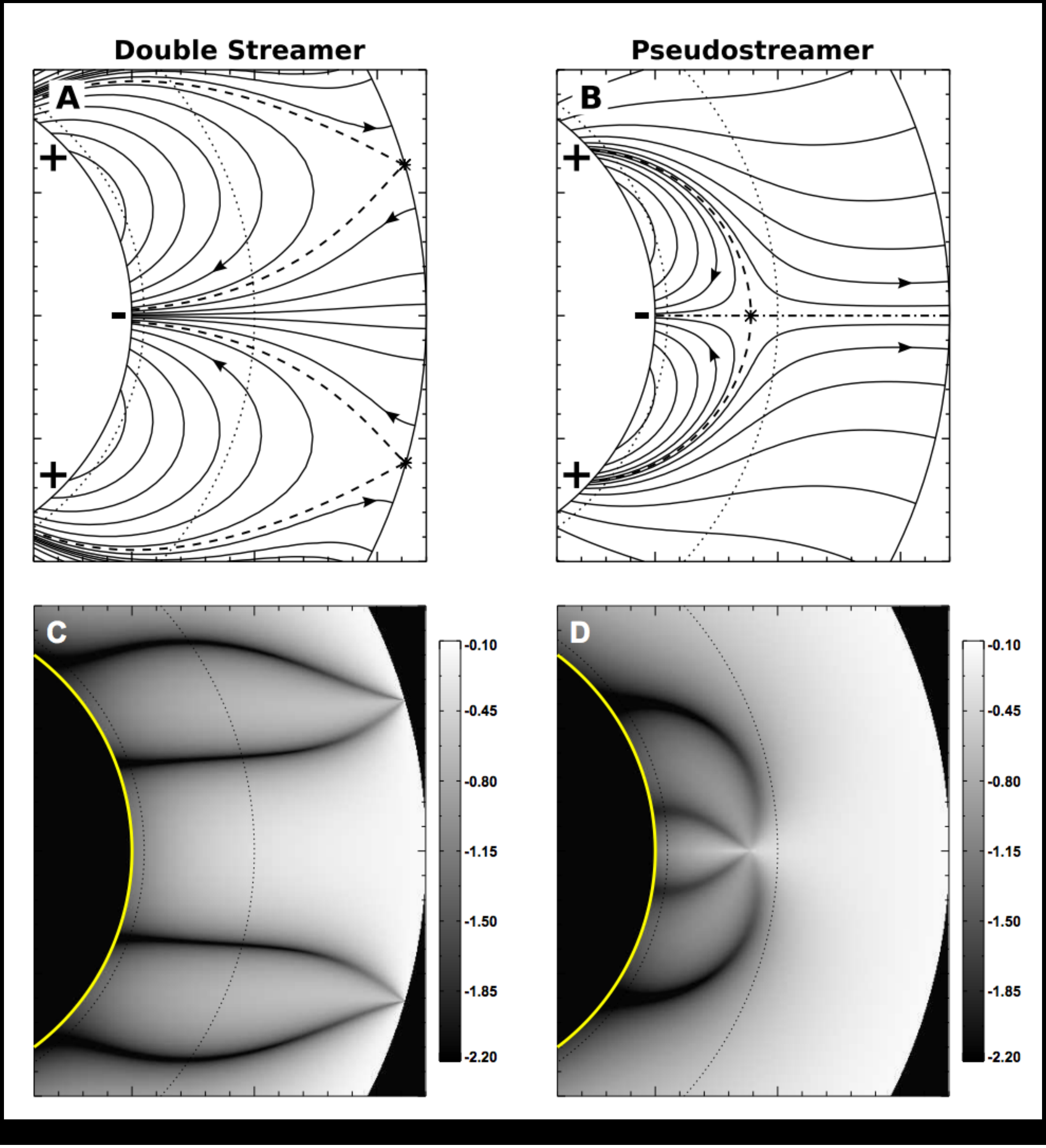
Van Vleck inversion in arcade

Flux rope axis

Bak-Steslicka et al., 2013

Pseudostreamers in linear polarization

Expected topology



L/I

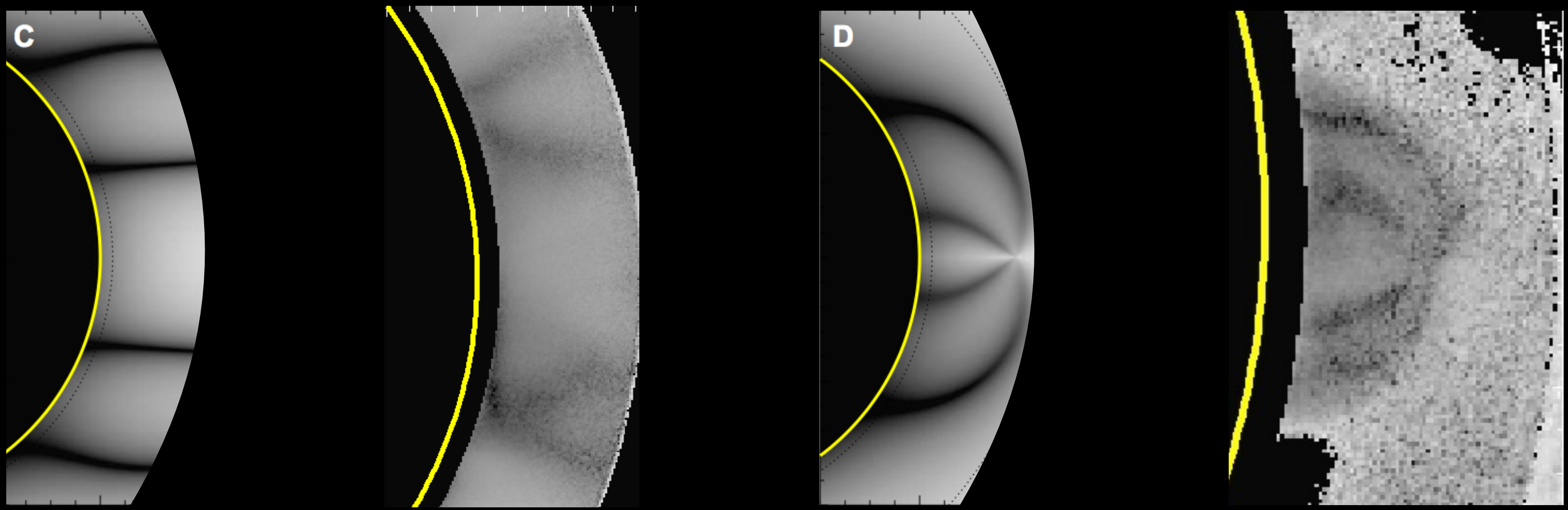
Rachmeler et al 2014

Pseudostreamers in linear polarization

Rachmeler et al 2016

CoMP observations vs models

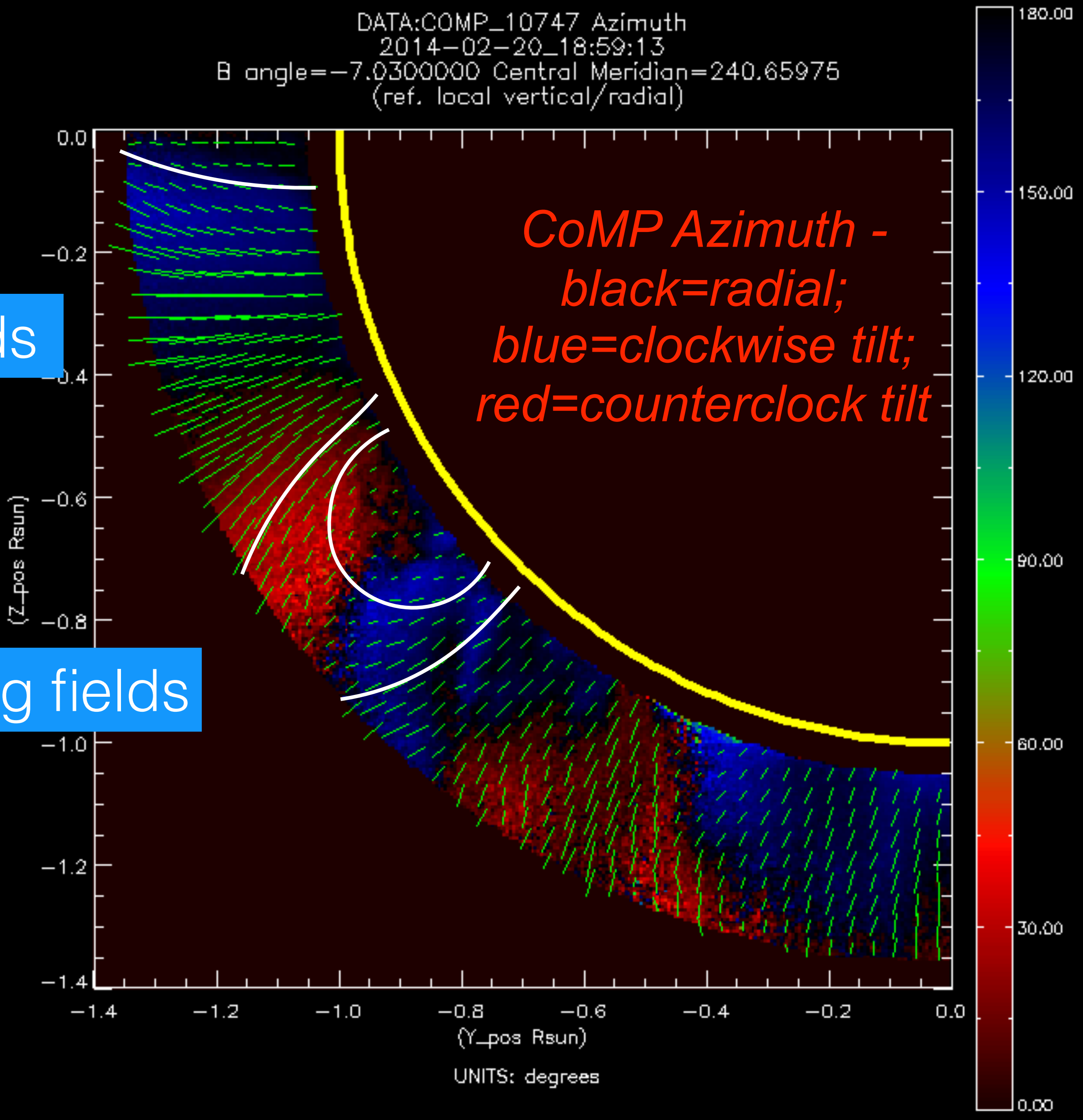
L/I



Double Streamer

Pseudostreamer

FORWARD: Observations

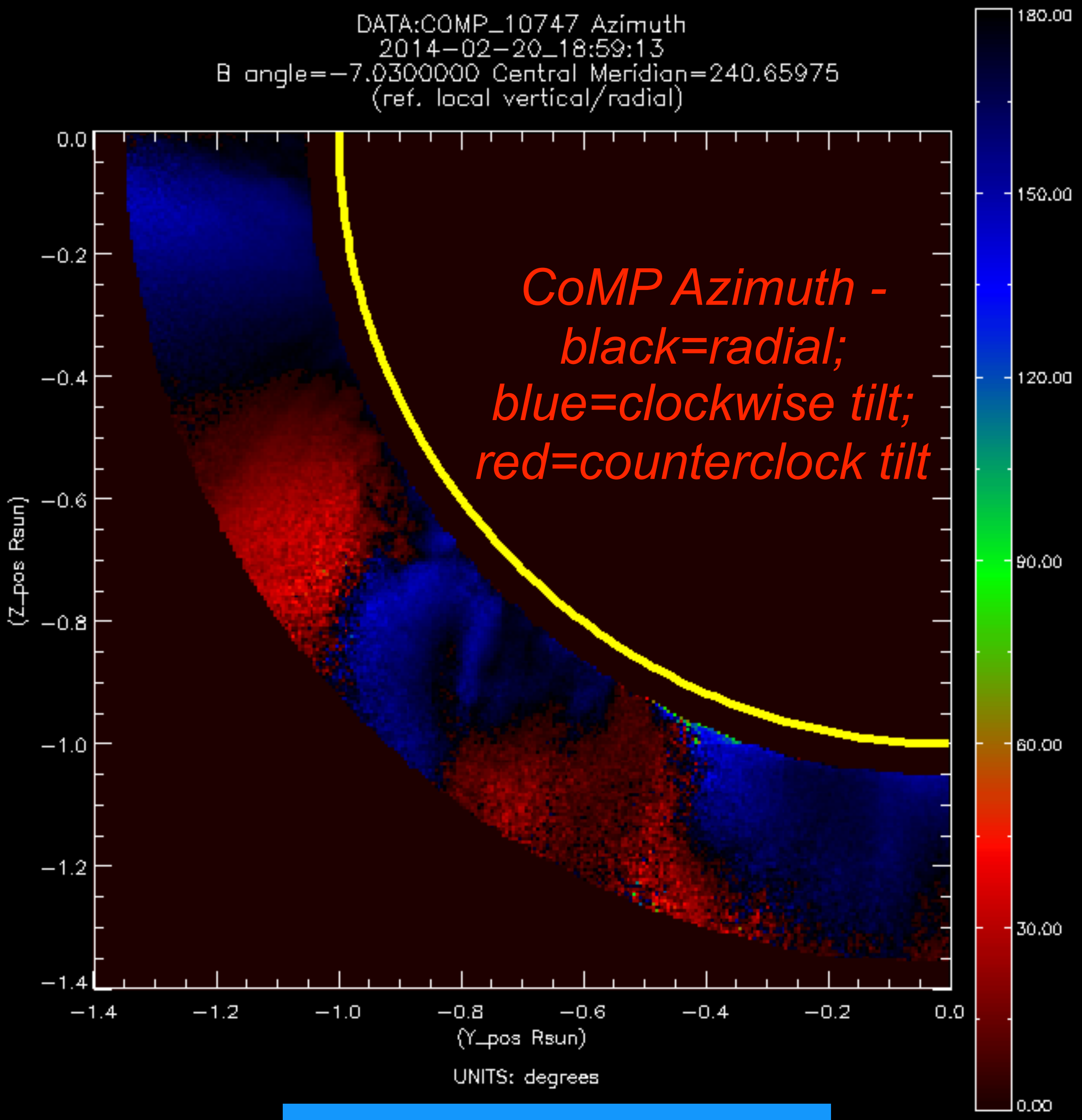


CoMP Azimuth - black=radial; blue=clockwise tilt; red=counterclock tilt

diverging fields

converging fields

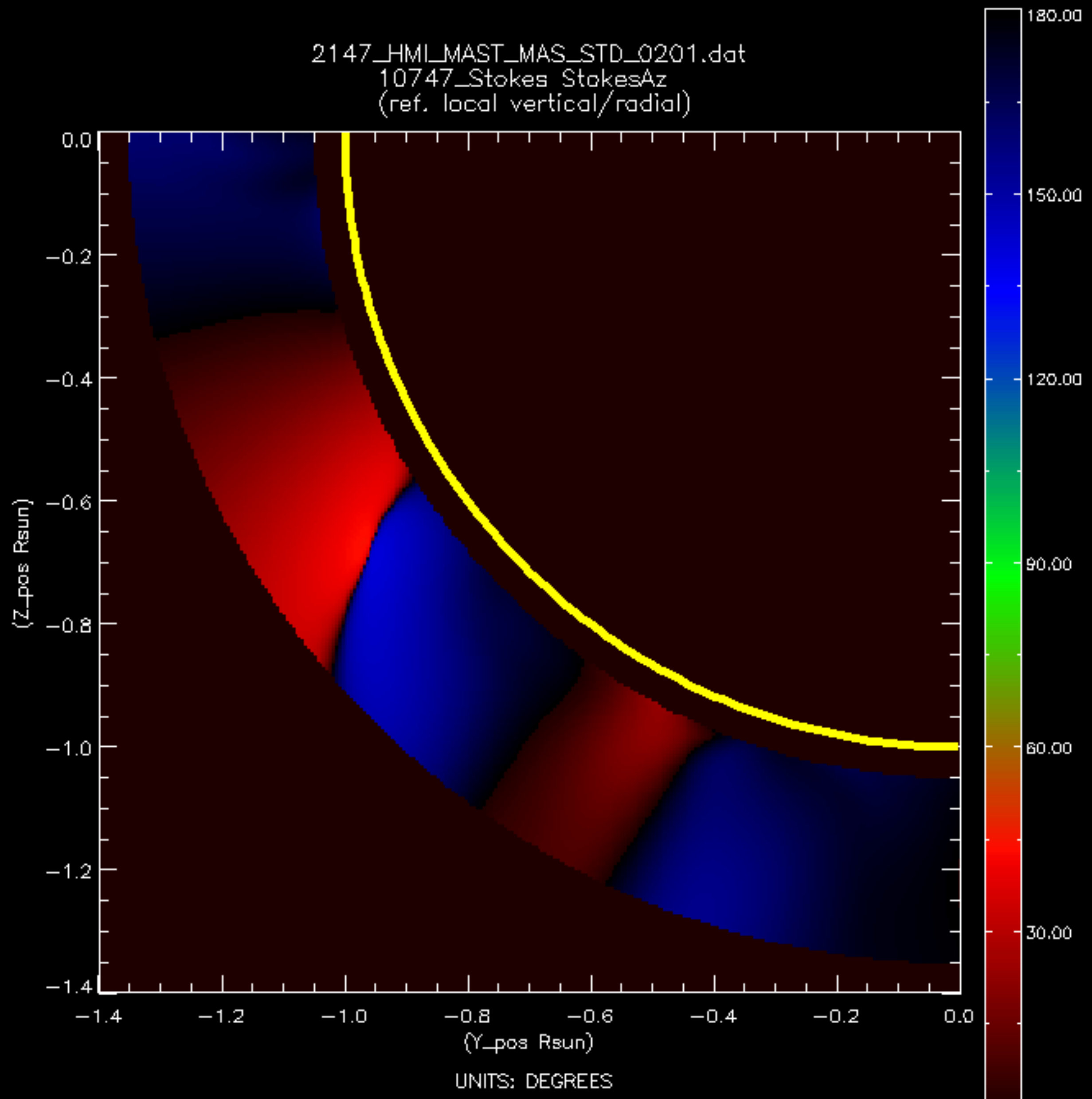
Non-radial expansion in linear polarization azimuth



CoMP Azimuth - black=radial; blue=clockwise tilt; red=counterclock tilt

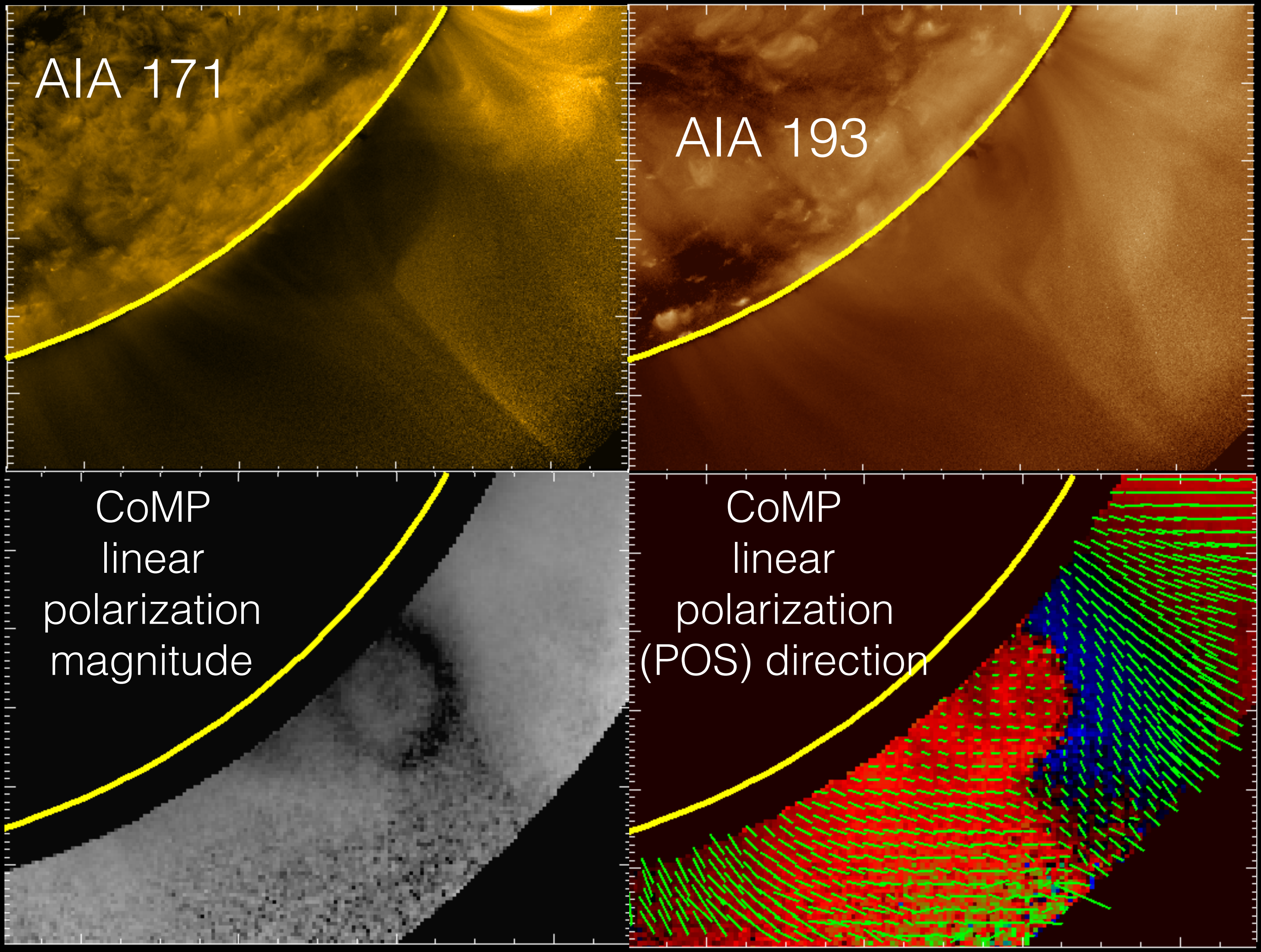
CoMP observations

Non-radial expansion in linear polarization azimuth



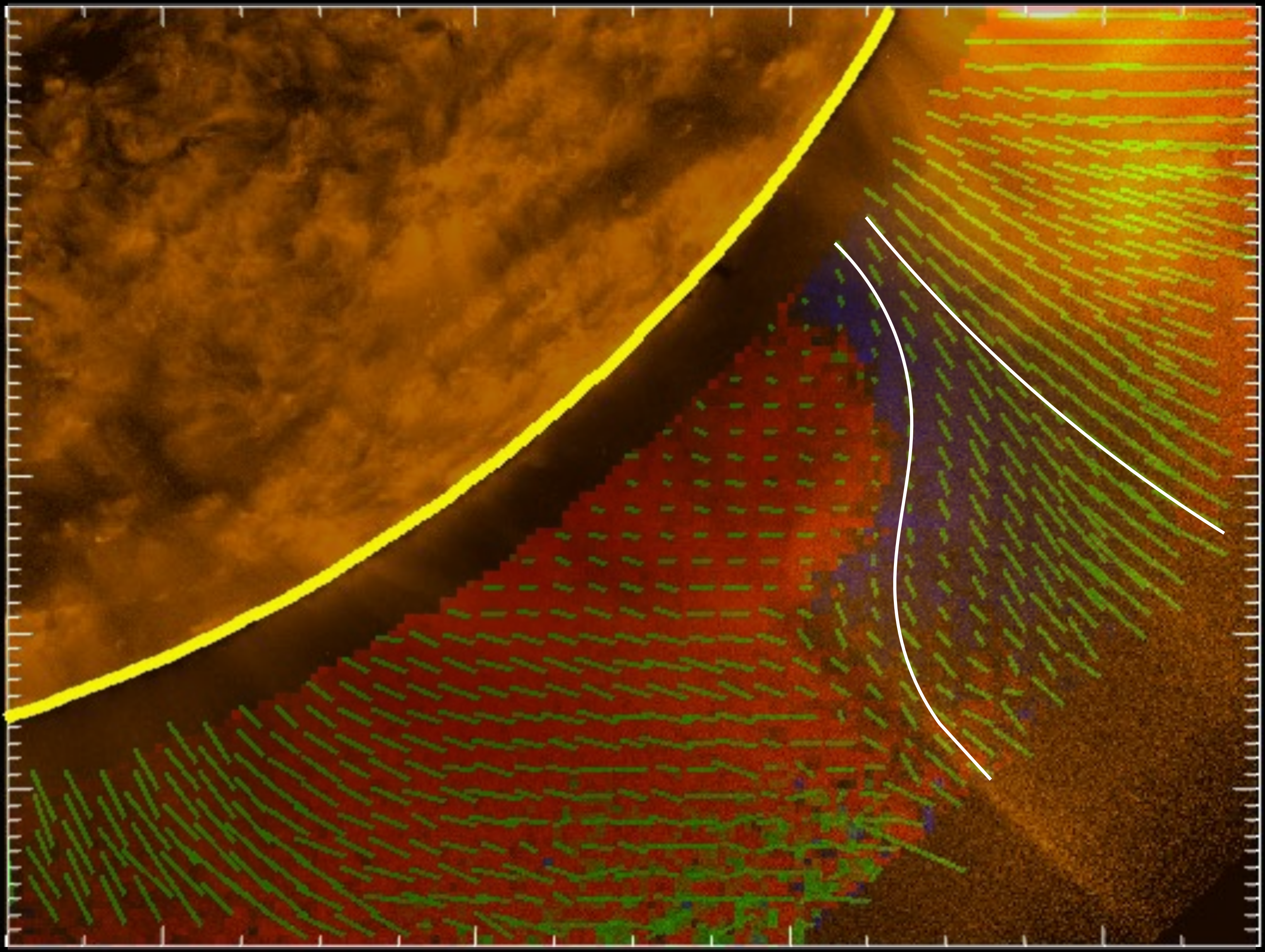
MAS model

FORWARD: Observations



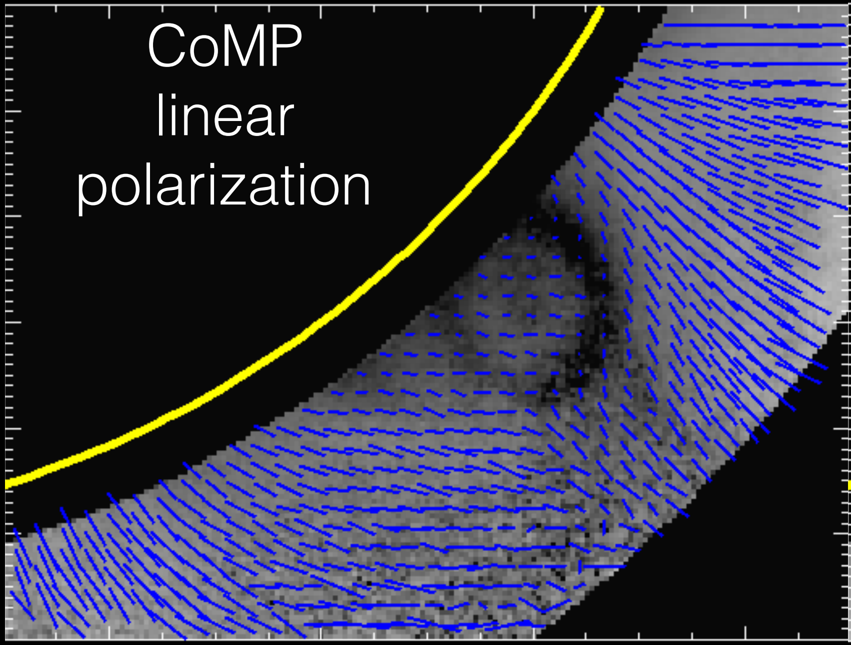
2015 April 18 Pseudostreamer

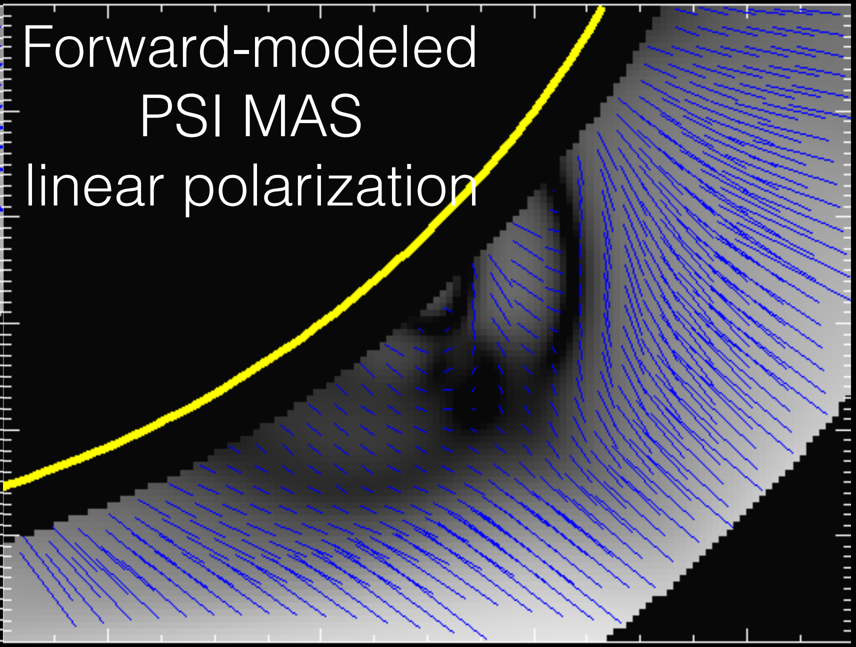
FORWARD: Observations



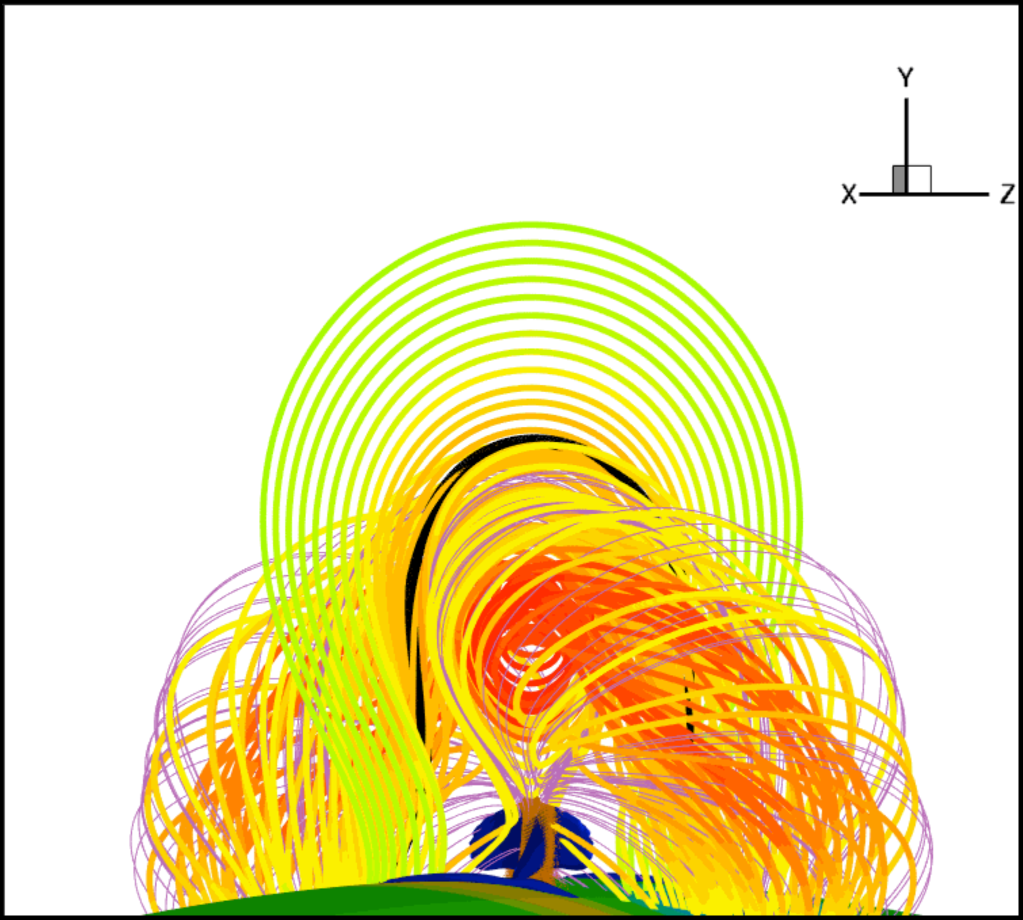
New diagnostic of expansion factor

FORWARD: Observations vs synthetic



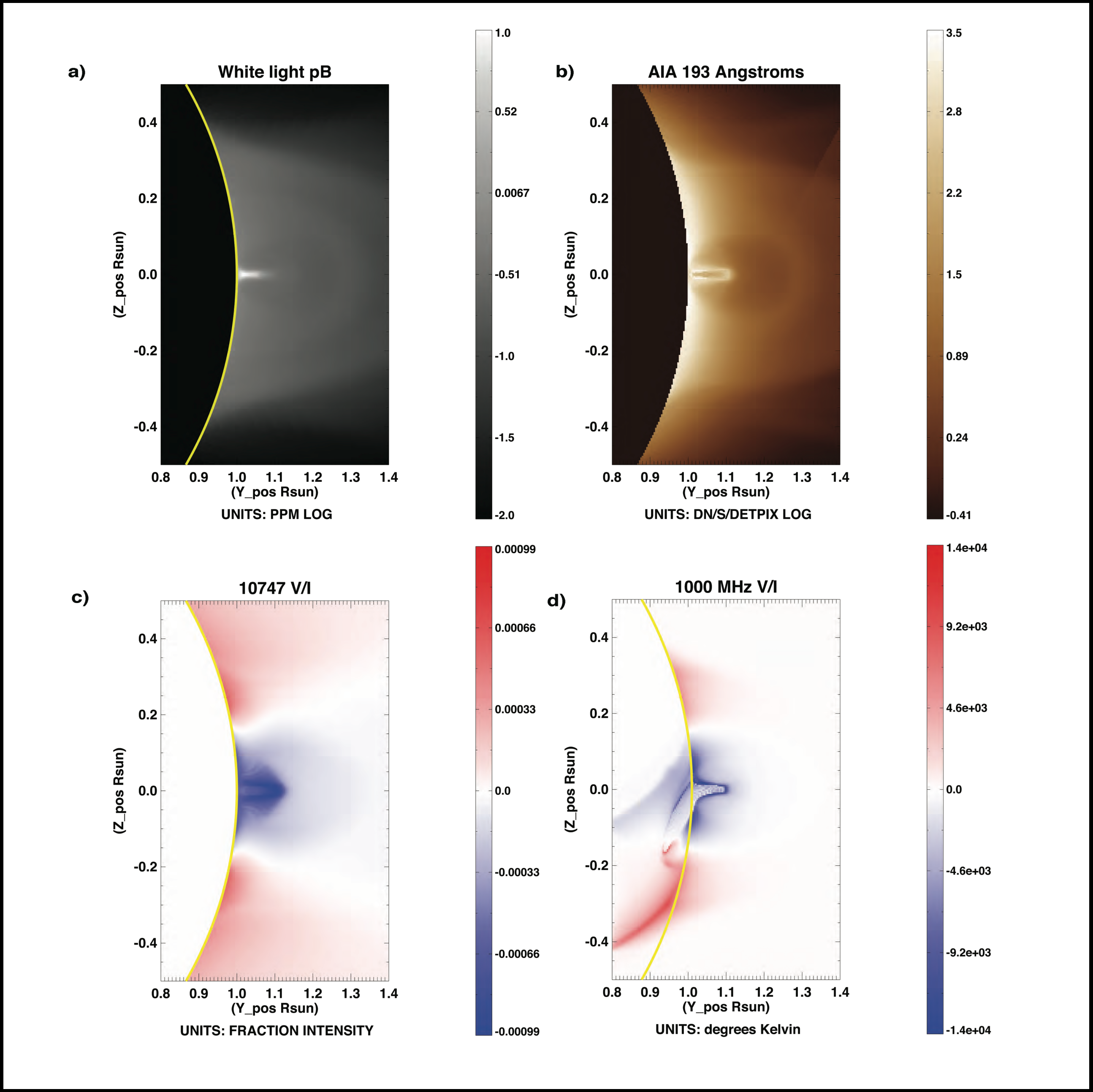


FORWARD: synthetic test beds

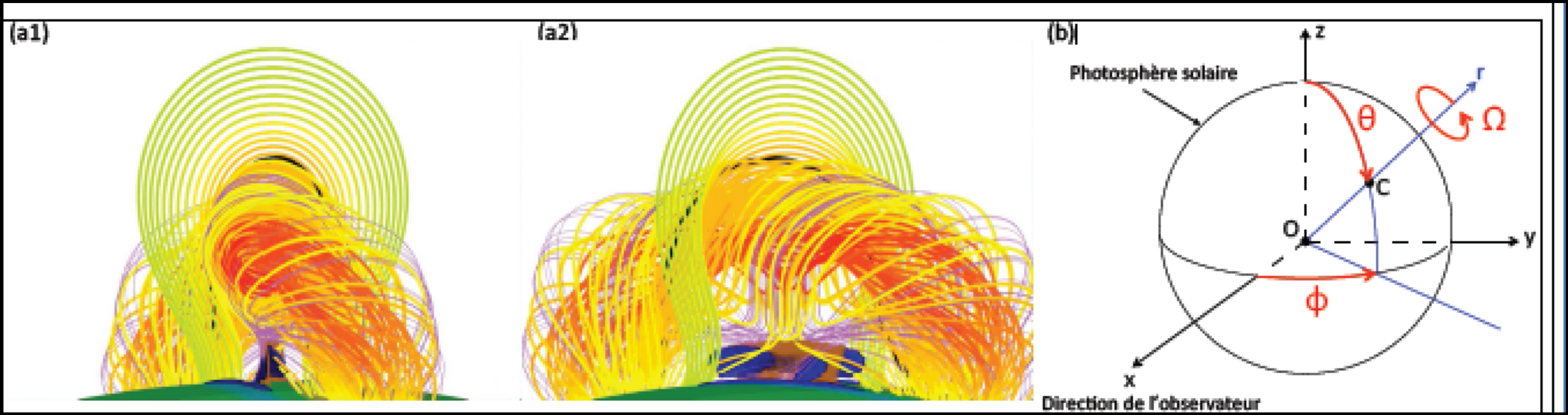


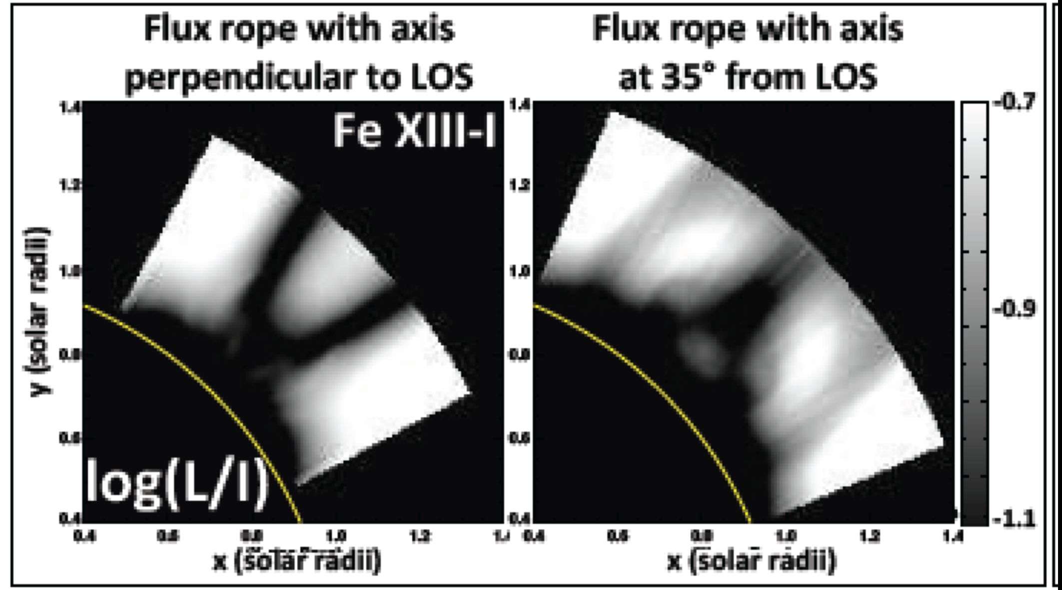
Fan, 2012

FORWARD: synthetic test beds



ROAM: Radial-basis-function Optimization Approximation Method





Using parameterized model, seek to regain "ground truth"

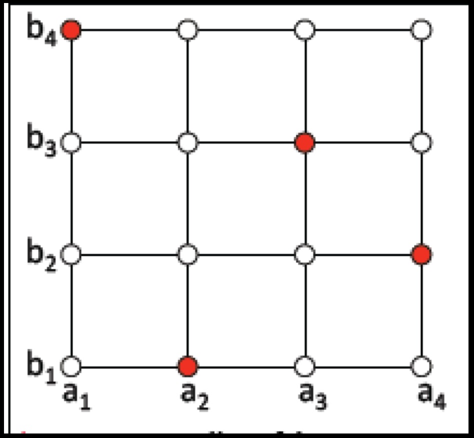
Dalmasse et al., 2016

ROAM: Radial-basis-function Optimization Approximation Method

Sparsely sample parameter space

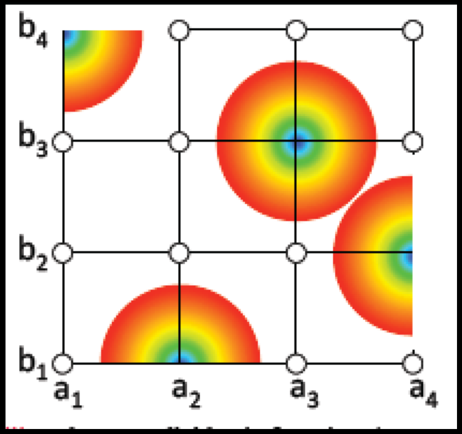
Evaluate model magnetic field and forward-modeled Stokes vector at each point

Calculate likelihood function (observations vs. model) at each point

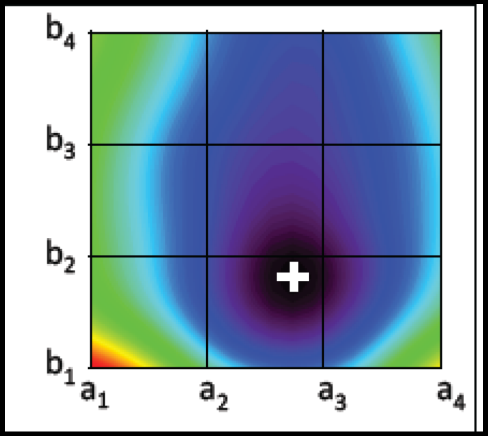


Place radial basis function (RBF) characterizing likelihood at each point

Interpolate —> create RBF reconstruction of the likelihood

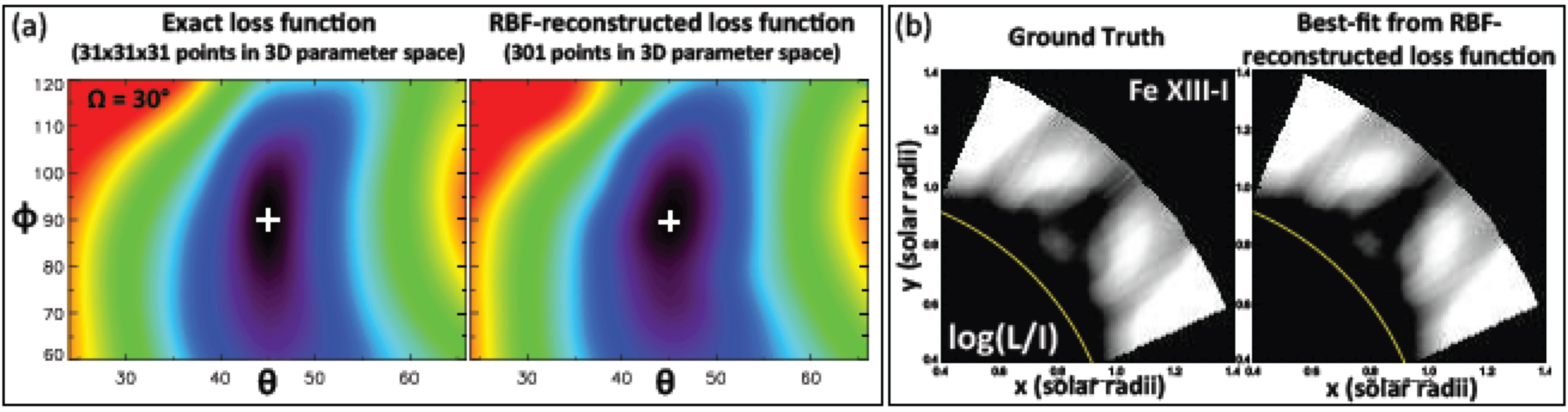


Maximize *interpolated surface* —> find best fit set of parameters



Dalmasse et al., 2016

ROAM: Radial-basis-function Optimization Approximation Method



The RBF reconstruction computed from 301 points in 3D parameter space is:

- **100 times faster** than a full grid search with 31^3 point
- **10_5 times faster** than a full grid search with 301^3 points.

The RBF reconstruction gives a very good approximation of the exact likelihood function (rms error ≈0.05)

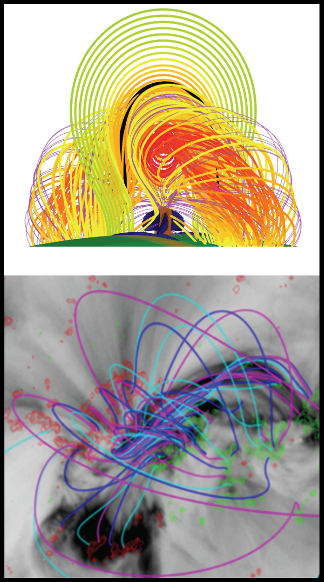
The best-fit parameters from the RBF reconstruction, **(45.0°; 89.9°; 30.3°)**, provide an accurate estimation of the ground truth, **(θ_{GT}; ϕ_{GT}; Ω_{GT}) = (45°; 90°; 30°)**.

The predicted polarization signal for the best-fit parameters obtained with the RBF reconstruction gives a good approximation of the ground truth; the error on the polarization signal is smaller than 0.005.

Dalmasse et al., 2016

DOCFM: next steps

Use flux-rope insertion method to reproduce ground-truth of Fan flux-rope synthetic test bed



Go global!