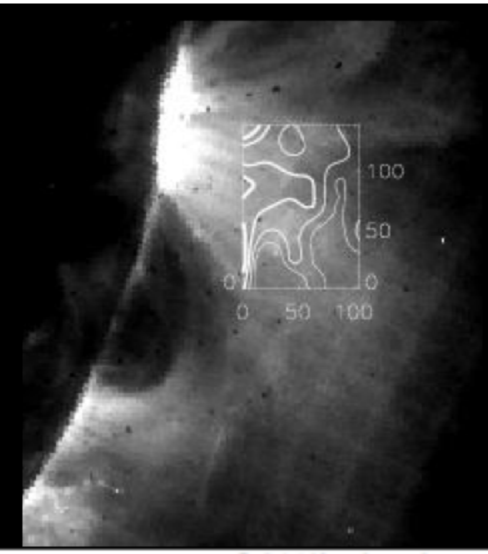
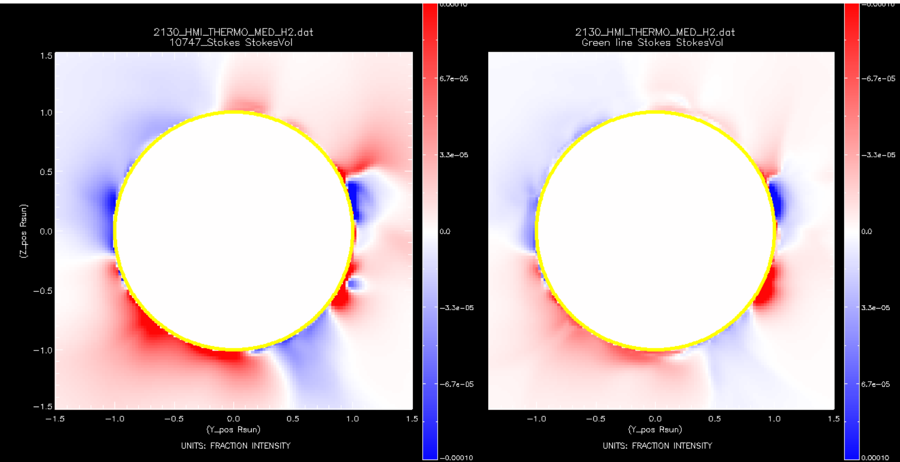
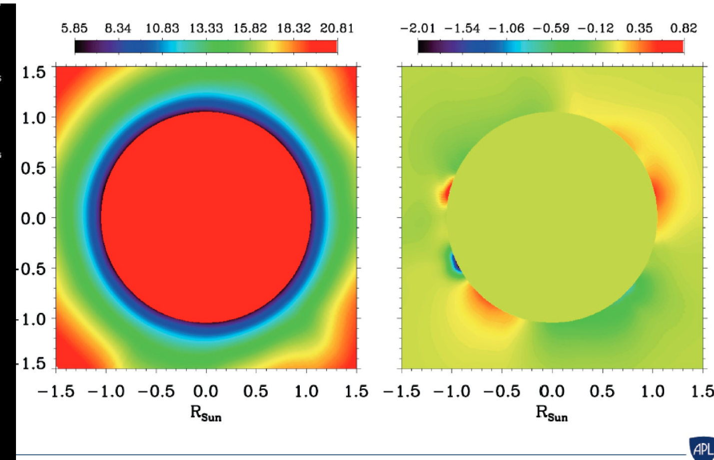
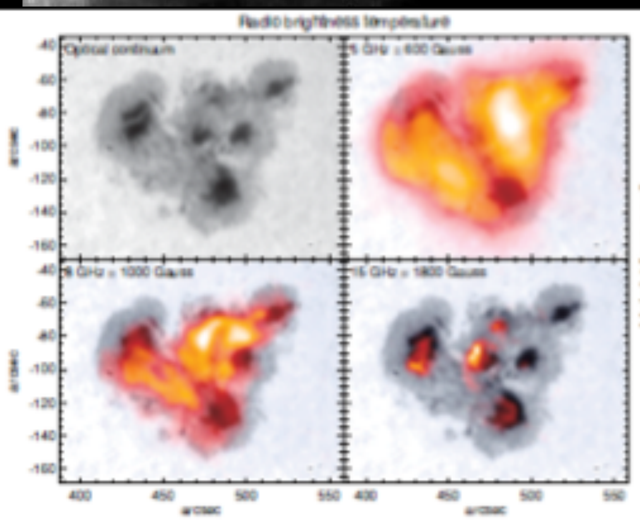
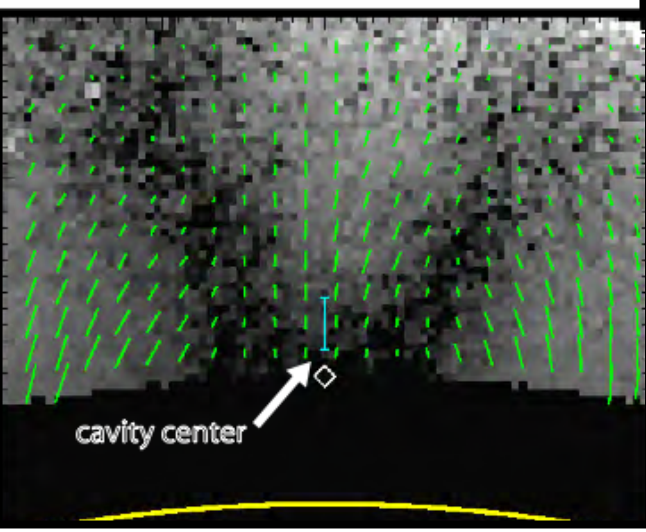








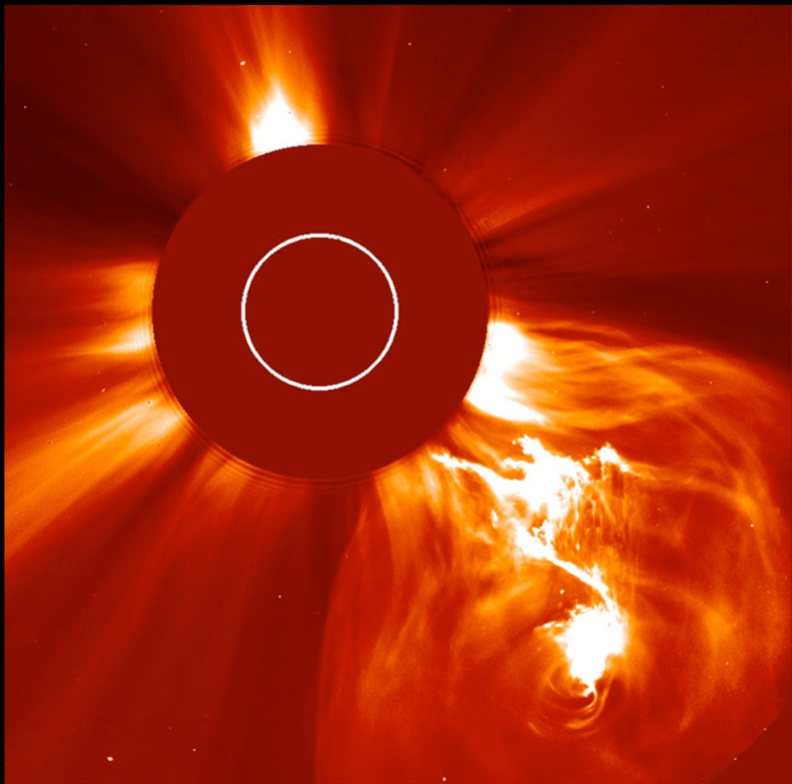


Magnetism Matters: Coronal Magnetometry Using Multiwavelength Polarimetry

Sarah Gibson

DOC-FM Team: Kevin Dalmasse, Ed De Luca, Giuliana de Toma, Yuhong Fan, Natasha Flyer, Duncan Mackay, Karen Meyer, Doug Nychka, Jenna Samra, Antonia Savcheva, Steve Tomczyk

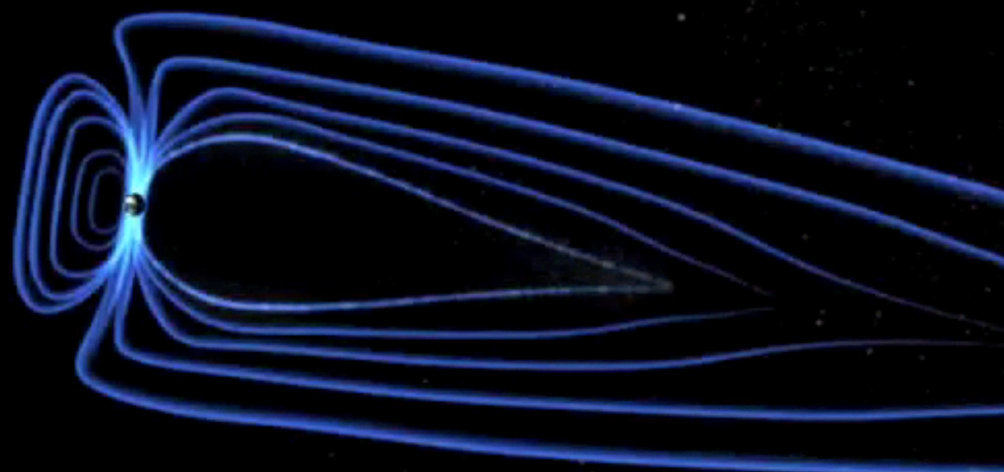
Why does the coronal magnetic field matter?



NASA

Controls the **storage and release of magnetic energy**, from Sun to Earth

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



Outline

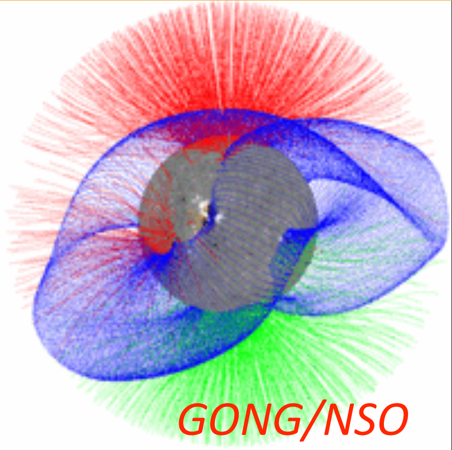
Boundary-driven models: strengths and limitations

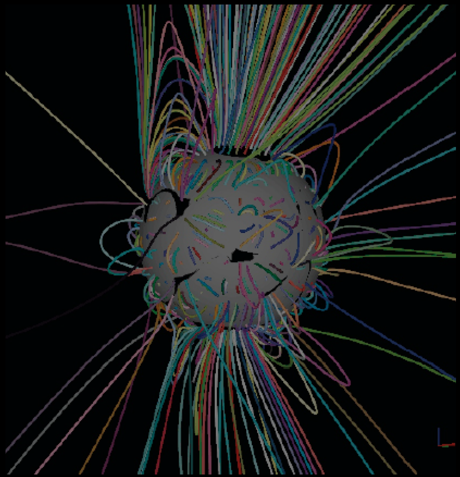
Coronal polarimetry: observations

Forward modeling: multiwavelength

Current work: DOC-FM and synthetic test beds

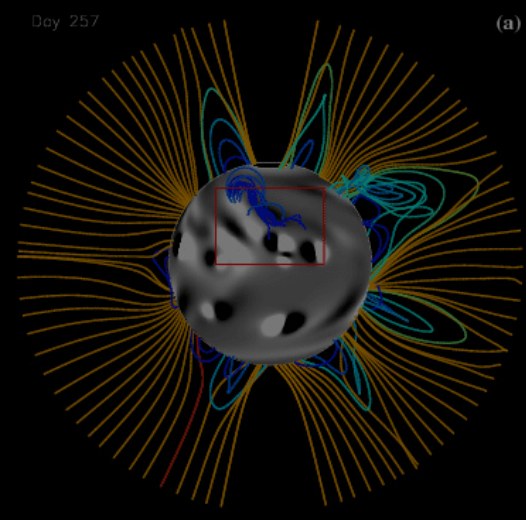
Boundary-driven models: strengths and limitations


GONG/NSO

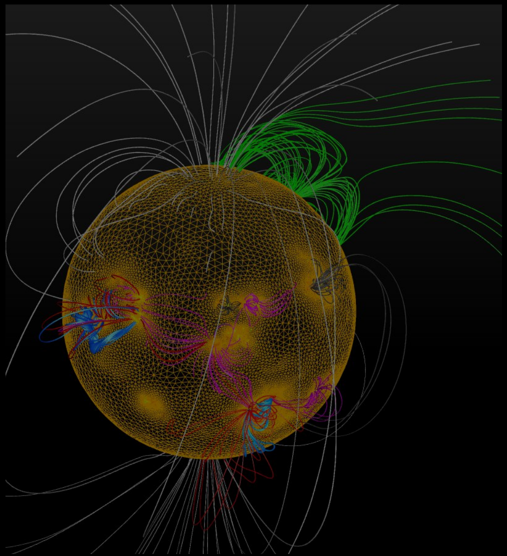

Predictive Science, Inc.

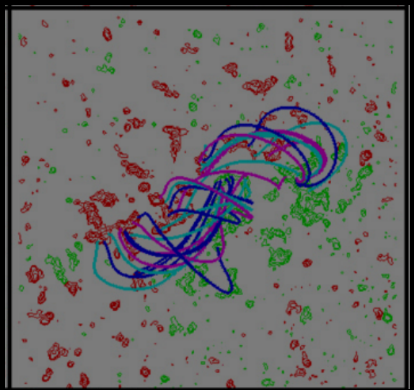
Potential-field source-surface global model:

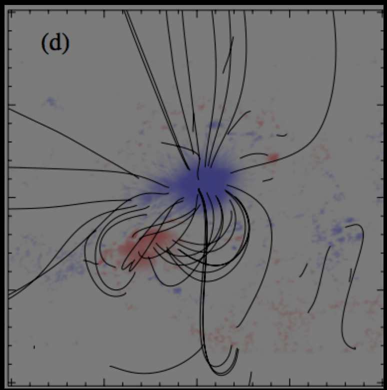
- Good first approximation of global field; no currents



Mackay & Yeates, 2012

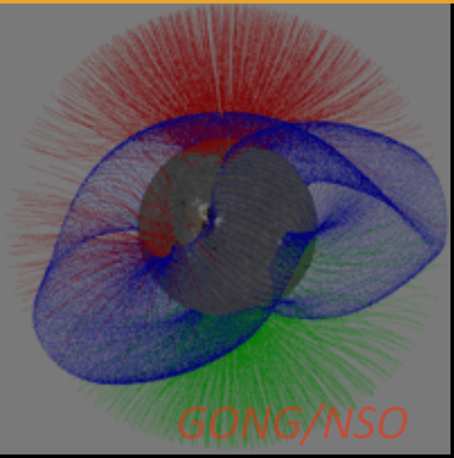

Amari et al., 2014

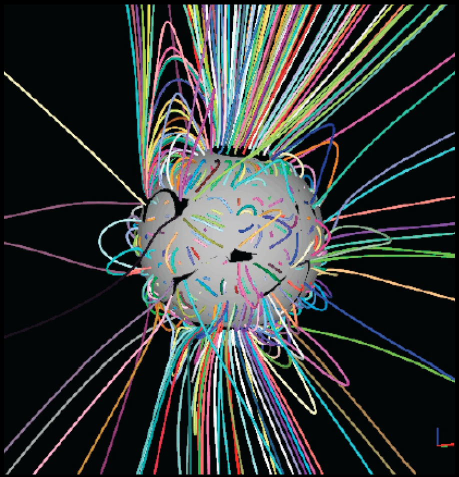

Savcheva and van Ballegooijen, 2009



Malanushenko et al., 2012

Boundary-driven models: strengths and limitations

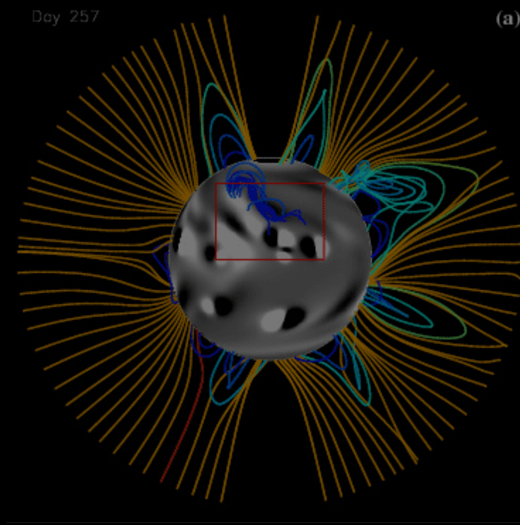




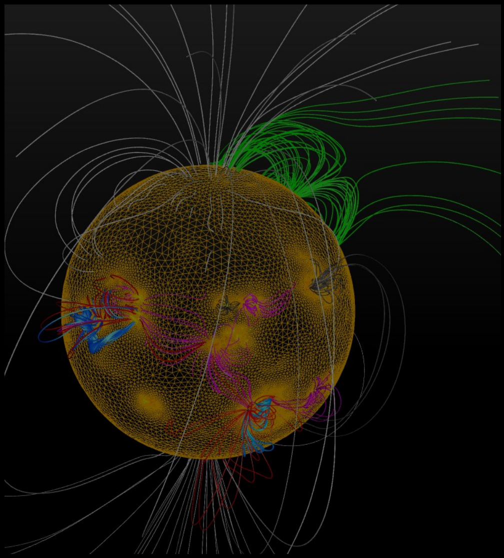
Predictive Science, Inc.

Global MHD model (LOS boundary field):

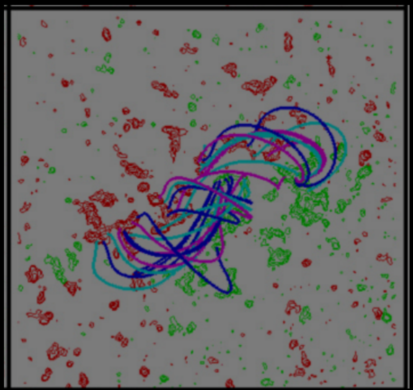
- Better solar-wind interface upper boundary; missing key currents



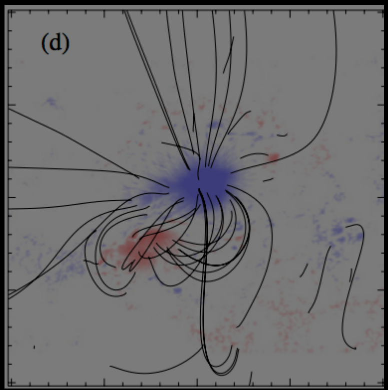
Mackay & Yeates, 2012



Amari et al., 2014

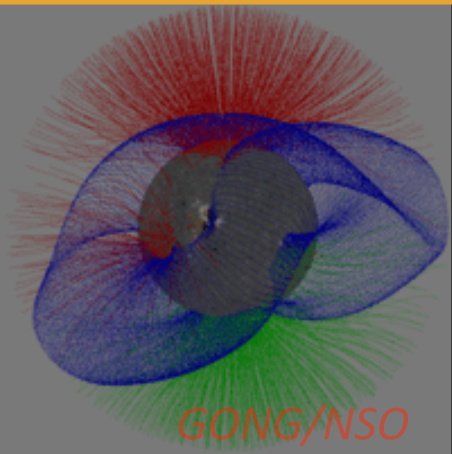


Savcheva and van Ballegooijen, 2009

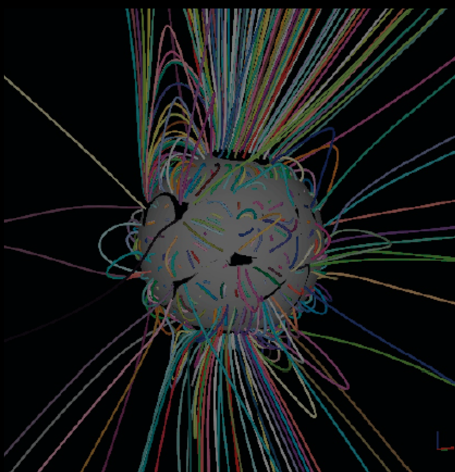


Malanushenko et al., 2012

Boundary-driven models: strengths and limitations



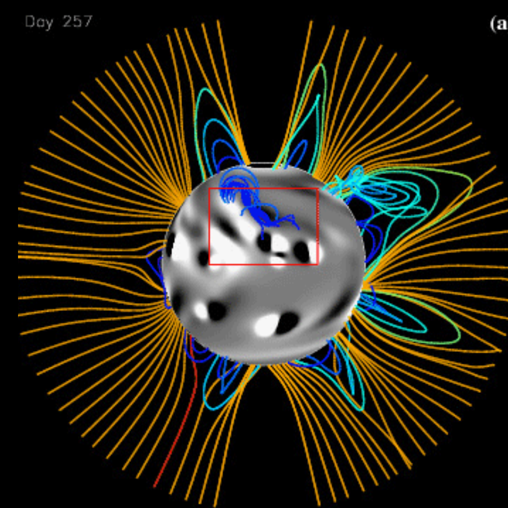
GONG/NSO



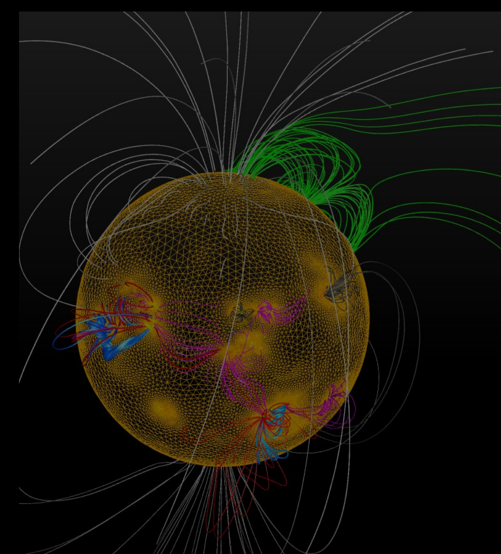
Predictive Science, Inc.

Global flux-transport magnetofrictional model

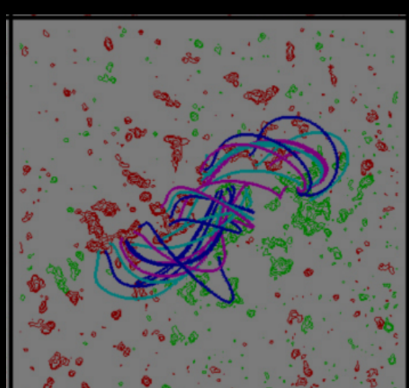
- Includes currents built up over time; simplified active-region emergence



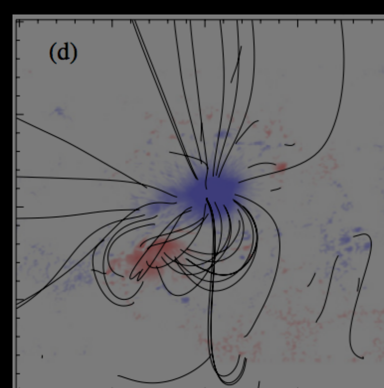
Mackay & Yeates, 2012



Amari et al., 2014

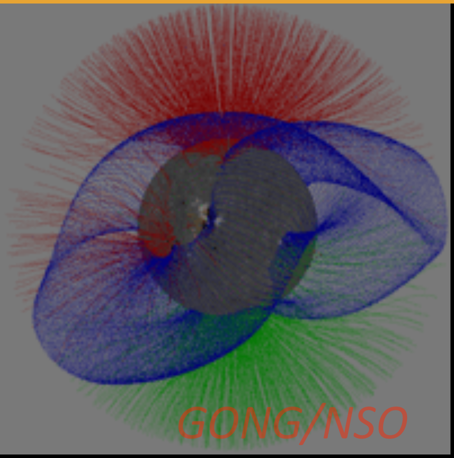


Savcheva and van Ballegooijen, 2009

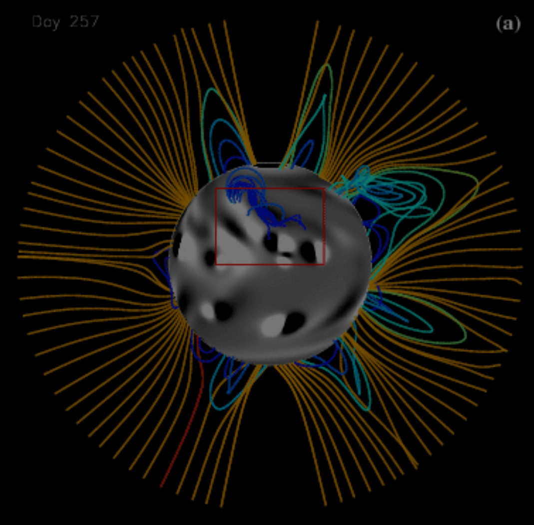


Malanushenko et al., 2012

Boundary-driven models: strengths and limitations



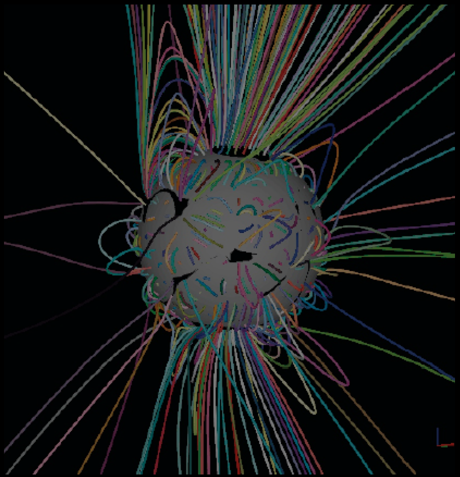
GONG/NSO



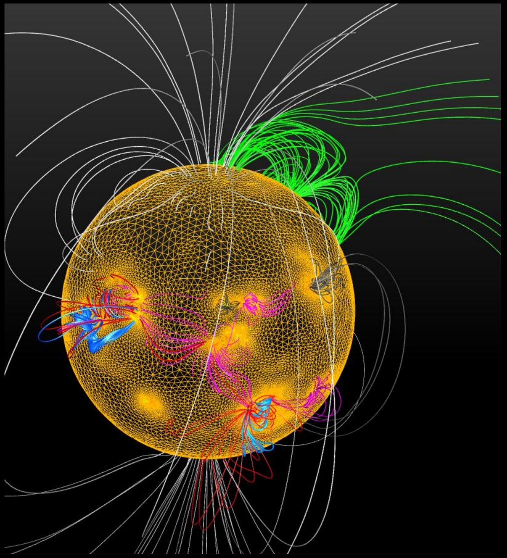
Mackay & Yeates, 2012

Non-linear force-free extrapolations (from vector boundary field)

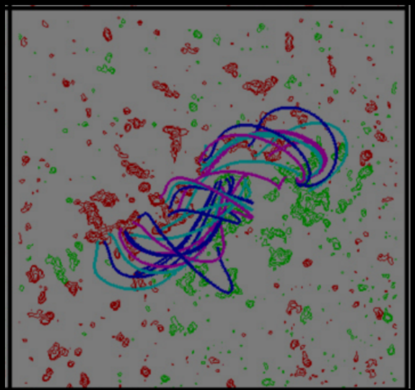
- Constrains currents as well as field; results sensitive to measurement uncertainties, departures from force-free



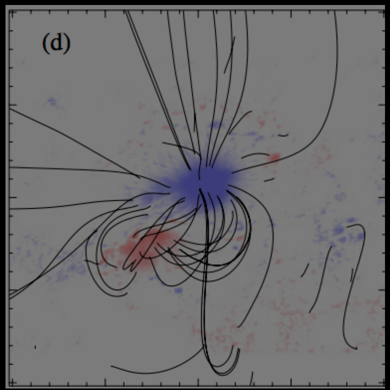
Predictive Science, Inc.



Amari et al., 2014

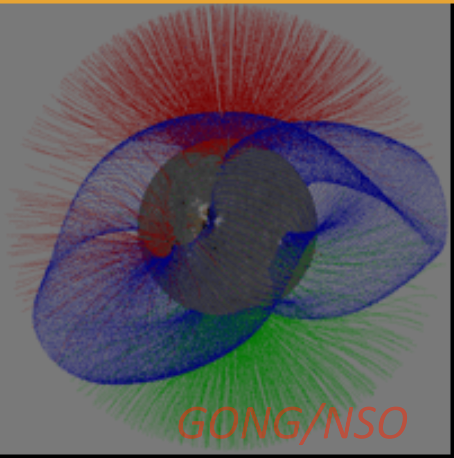


Savcheva and van Ballegooijen, 2009

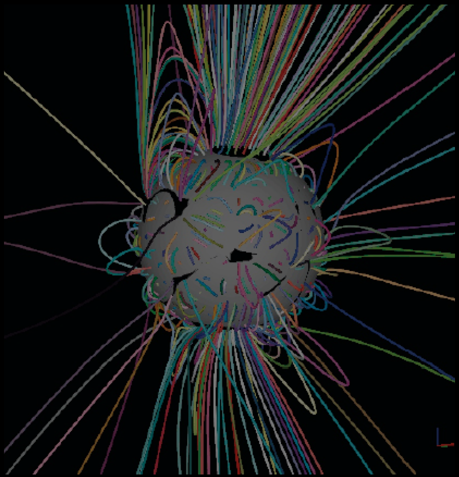


Malanushenko et al., 2012

Boundary-driven models: strengths and limitations



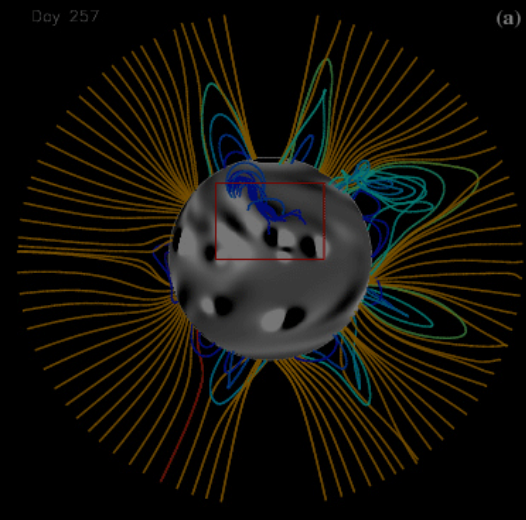
GONG/NSO



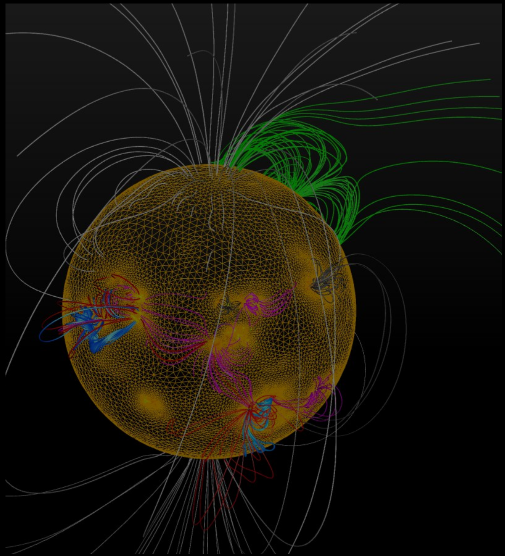
Predictive Science, Inc.

Non-linear force-free extrapolations with coronal constraints

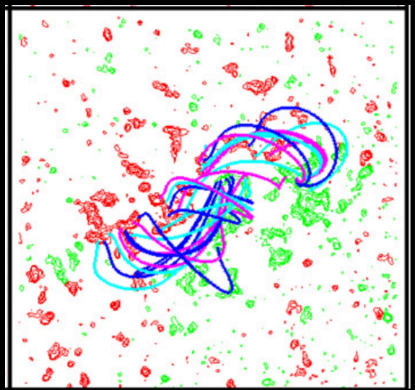
- Information from coronal loops constrains currents; so far not global



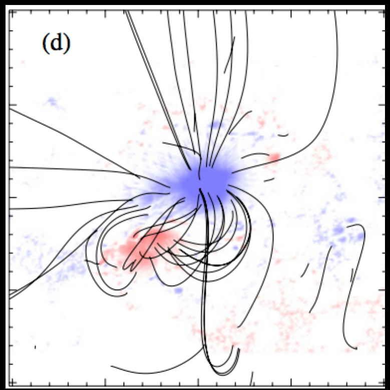
Mackay & Yeates, 2012



Amari et al., 2014



Savcheva and van Ballegooijen, 2009



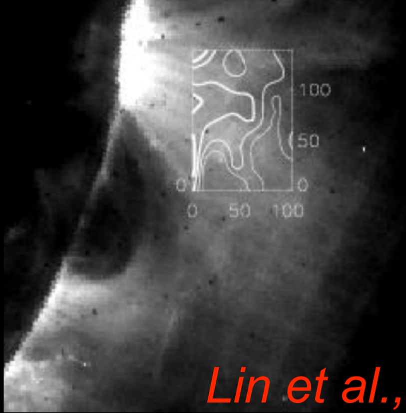
Malanushenko et al., 2012

But couldn't we measure the magnetic field in the corona itself?

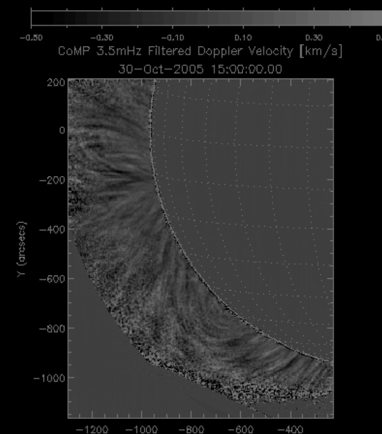
Coronal polarimety

Coronal polarimetry: observations

Contours of B_{los}: 4, 2, 0, -2 G



Lin et al., 2004

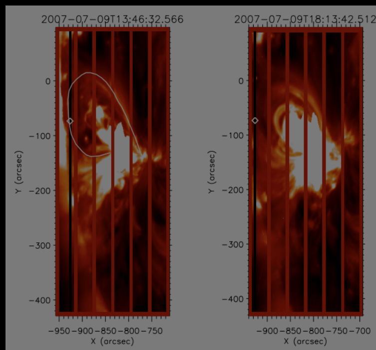


Tomczyk et al. 2007

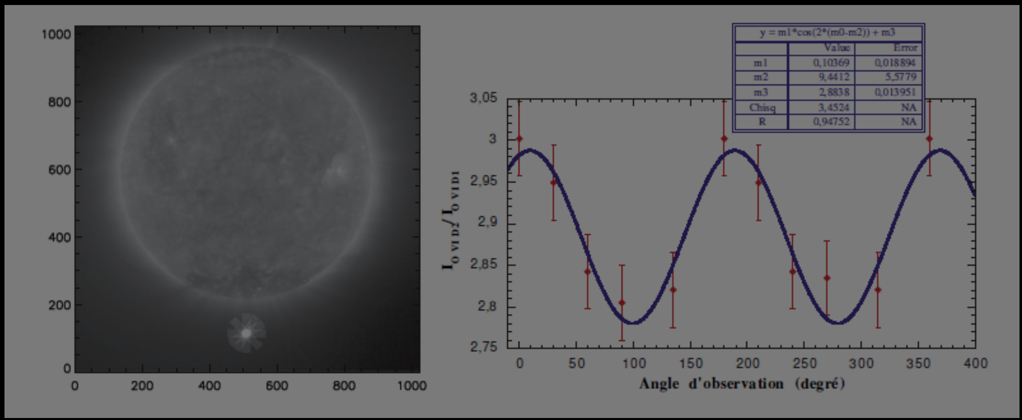
Infrared Stokes polarimetry
(Zeeman and Saturated Hanle):

- Circular polarization ~ $\mathbf{B_{los}}$
- Linear polarization: $\mathbf{B_{pos}}$ direction

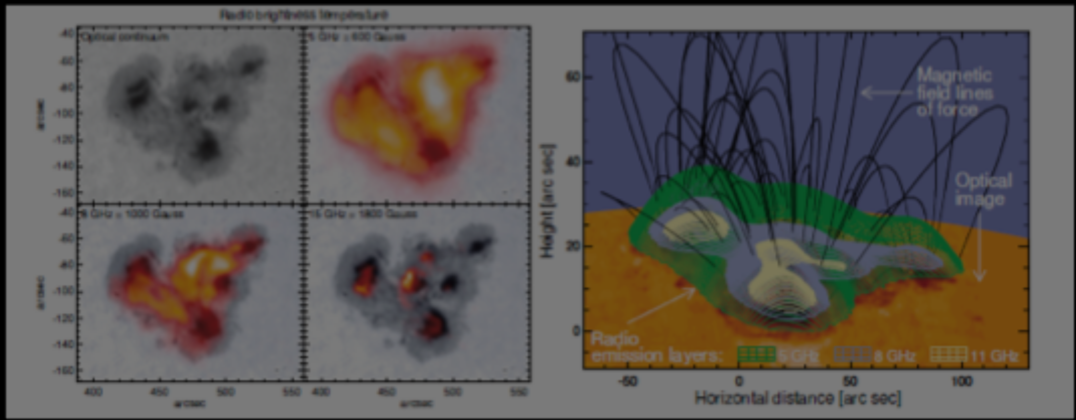
Tomczyk et al. 2008



van Doorsselaere, et al, 2008

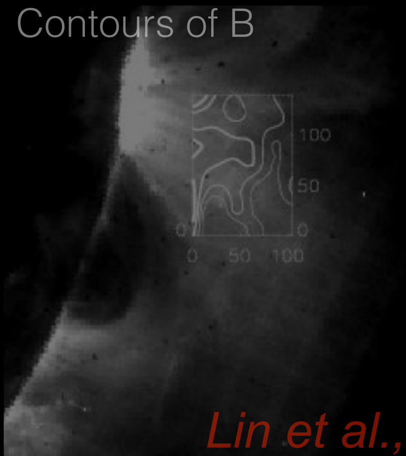


Raouafi et al 2002



Lee, 2007

Coronal polarimetry: observations

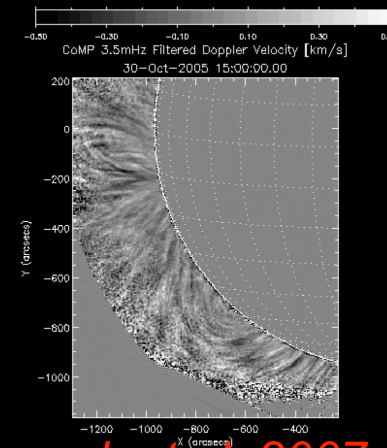


Lin et al., 2004

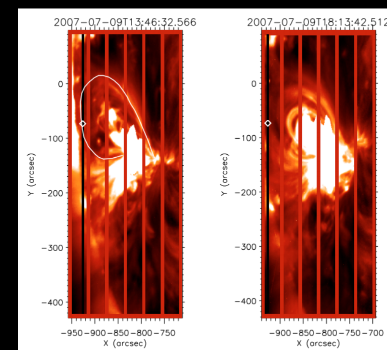
Tomczyk et al. 200

MHD waves - IR and EUV:

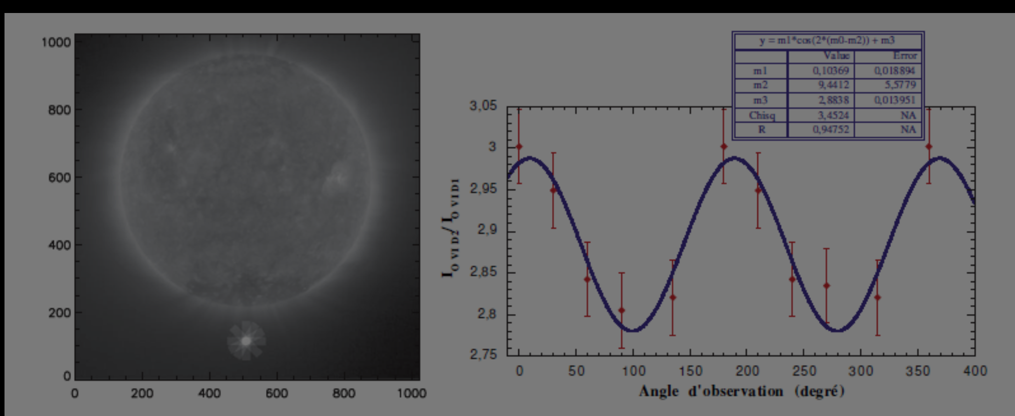
- Phase speed ~ |**B**|



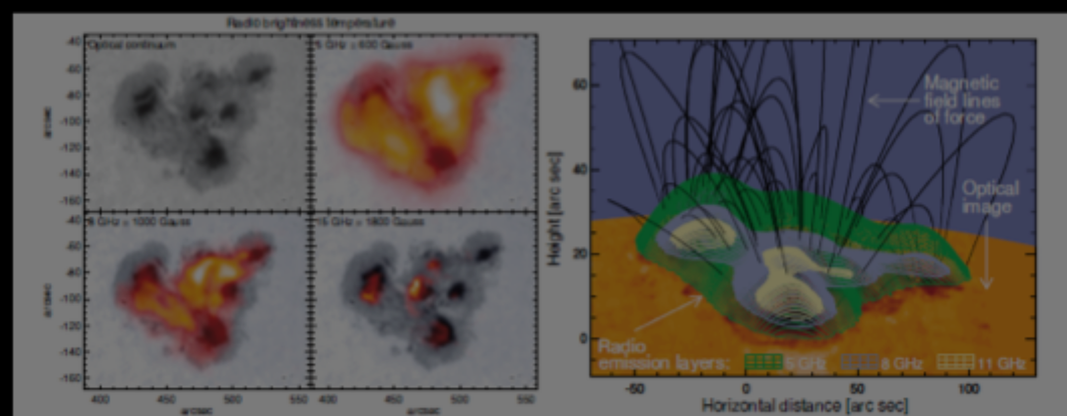
Tomczyk et al. 2007



van Doorsselaere, et al, 2008

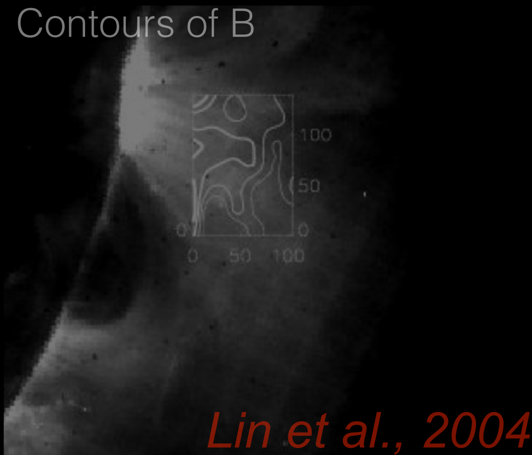


Raouafi et al 2002

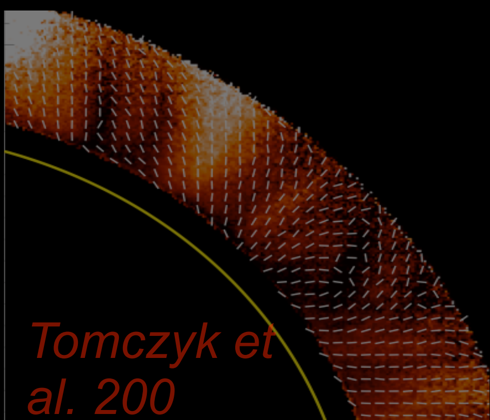


Lee, 2007

Coronal polarimetry: observations



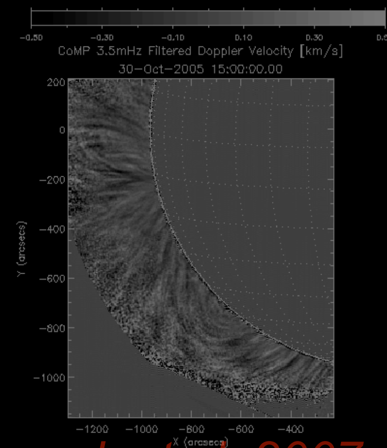
Lin et al., 2004



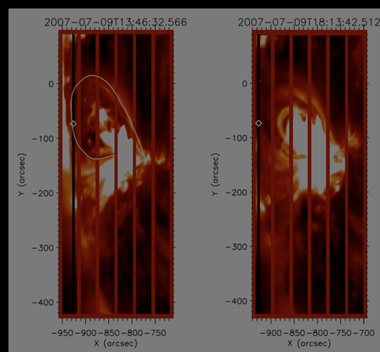
Tomczyk et al. 200

Radio gyroresonance:

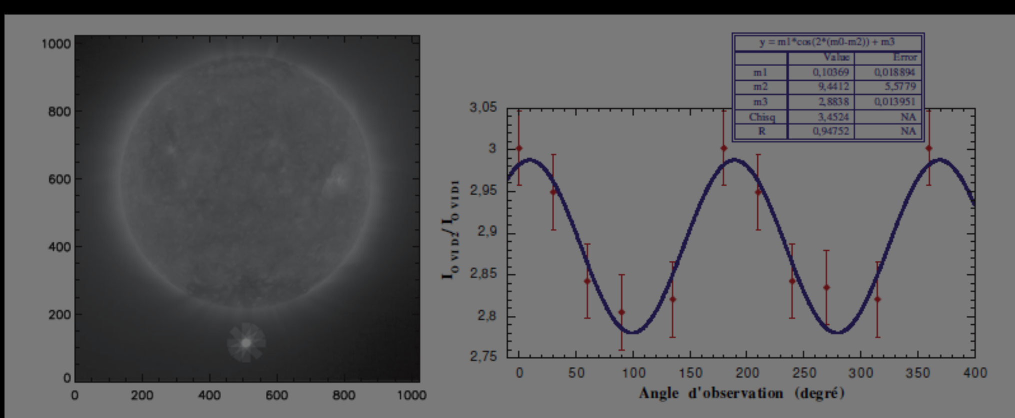
- Isogauss surface: |B| scales with frequency



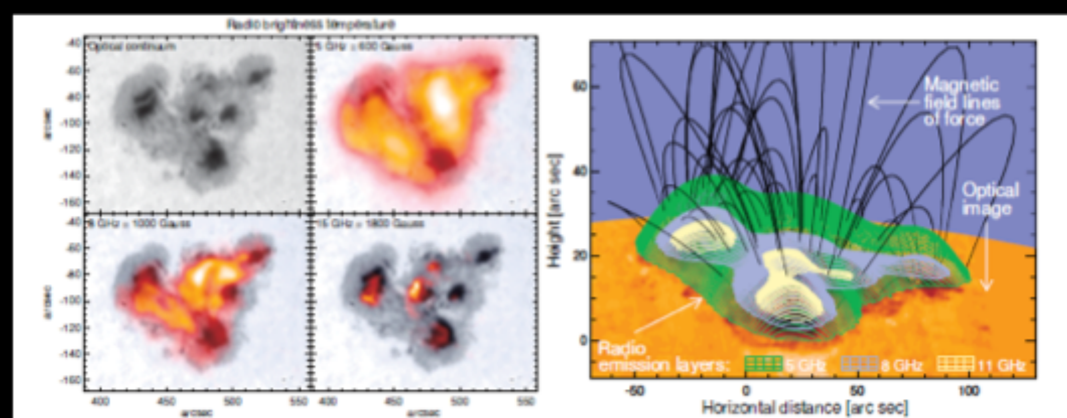
Tomczyk et al. 2007



van Doorsselaere, et al, 2008

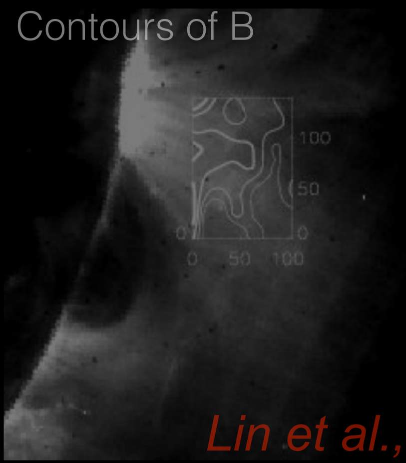


Raouafi et al 2002

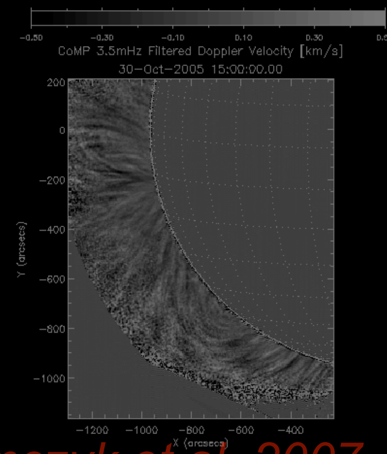


Lee, 2007

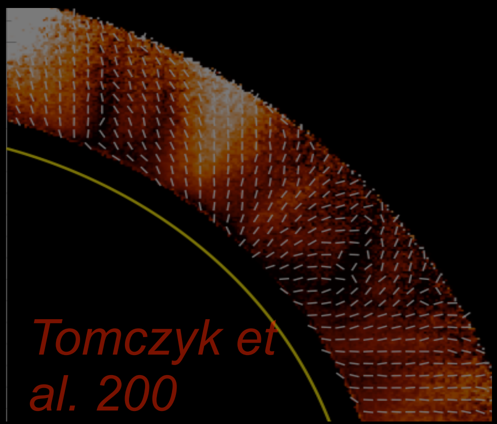
Coronal polarimetry: observations



Lin et al., 2004



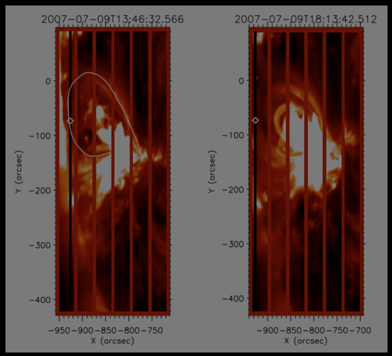
Tomczyk et al. 2007



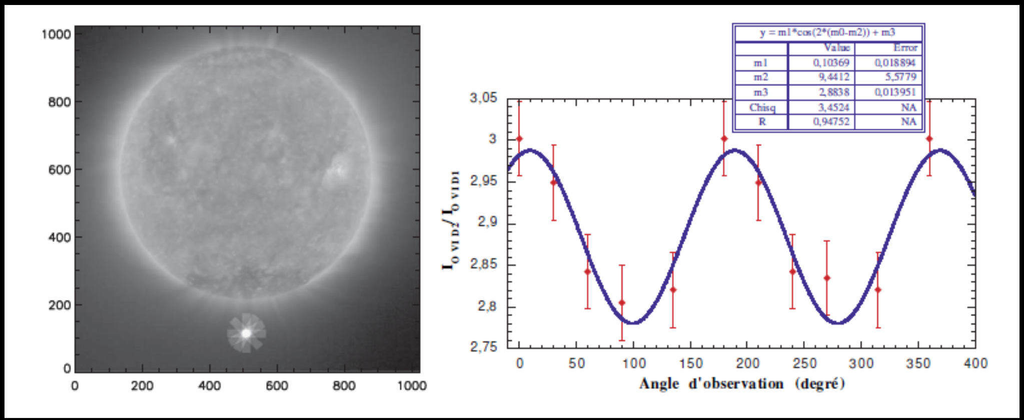
Tomczyk et al. 200

UV unsaturated Hanle:

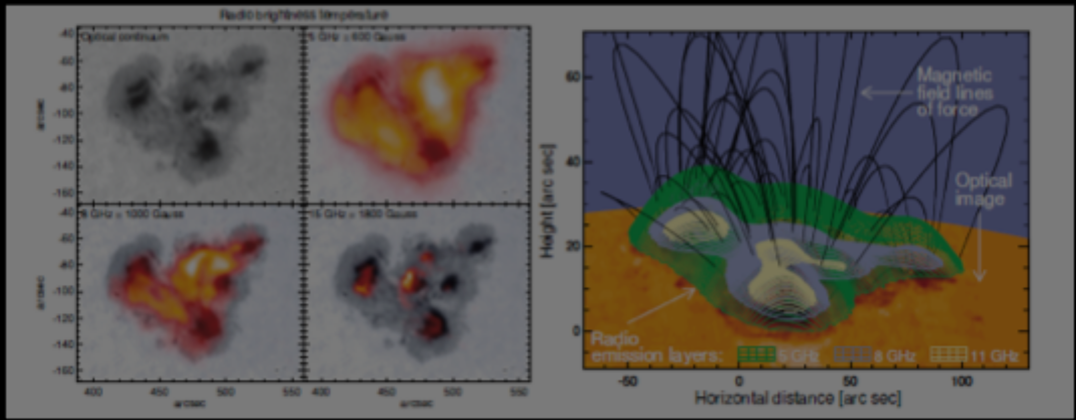
- linear polarization modified (reduced, rotated) by magnetic fields



van Doorsselaere, et al, 2008



Raouafi et al 2002



Lee, 2007

Coronal polarimetry: observations

Multiwavelength data have complementarities:

- sensitive to different aspects of magnetic field (**B_{los}, |B|, B_{POS},** POS direction)
- sensitive to either weak or strong field, appropriate for disk or limb
- dependent (in different ways) on density, temperature, velocity
- dependent (in different ways) on field variation along LOS

So how do we use all this information?

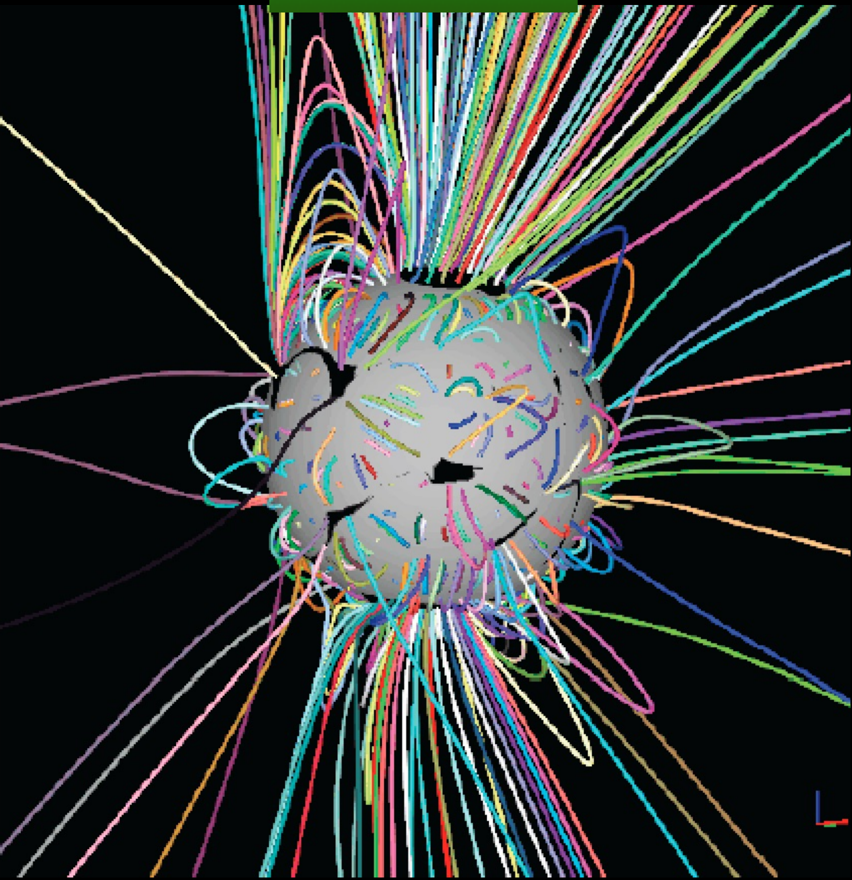
First step in any inverse method: a well-defined forward problem

FORWARD SolarSoft IDL package

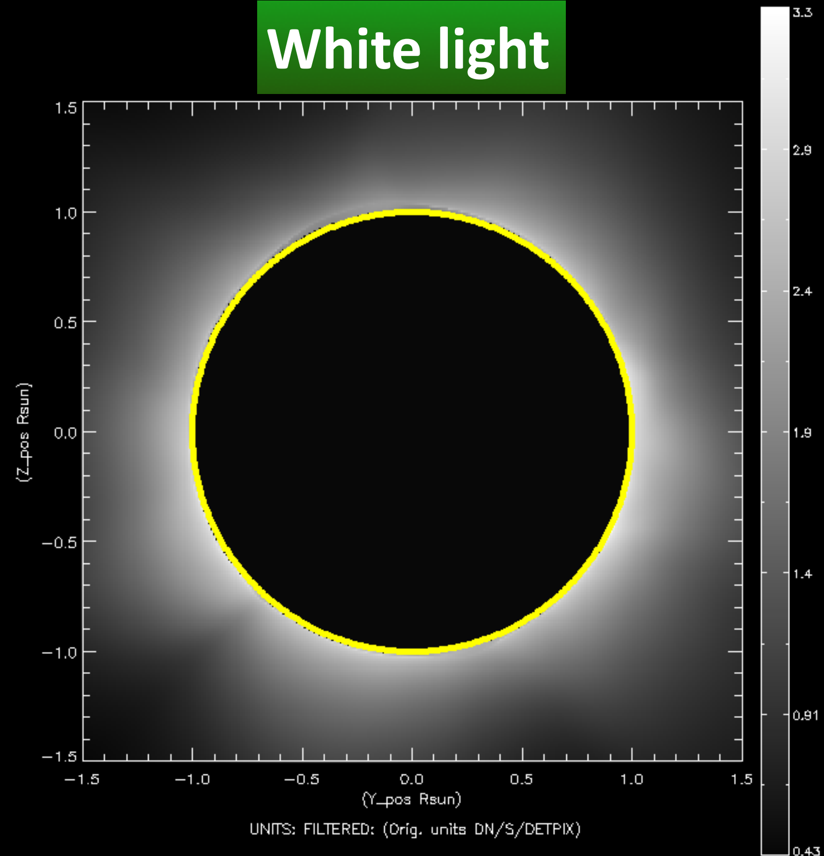
Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS



White light

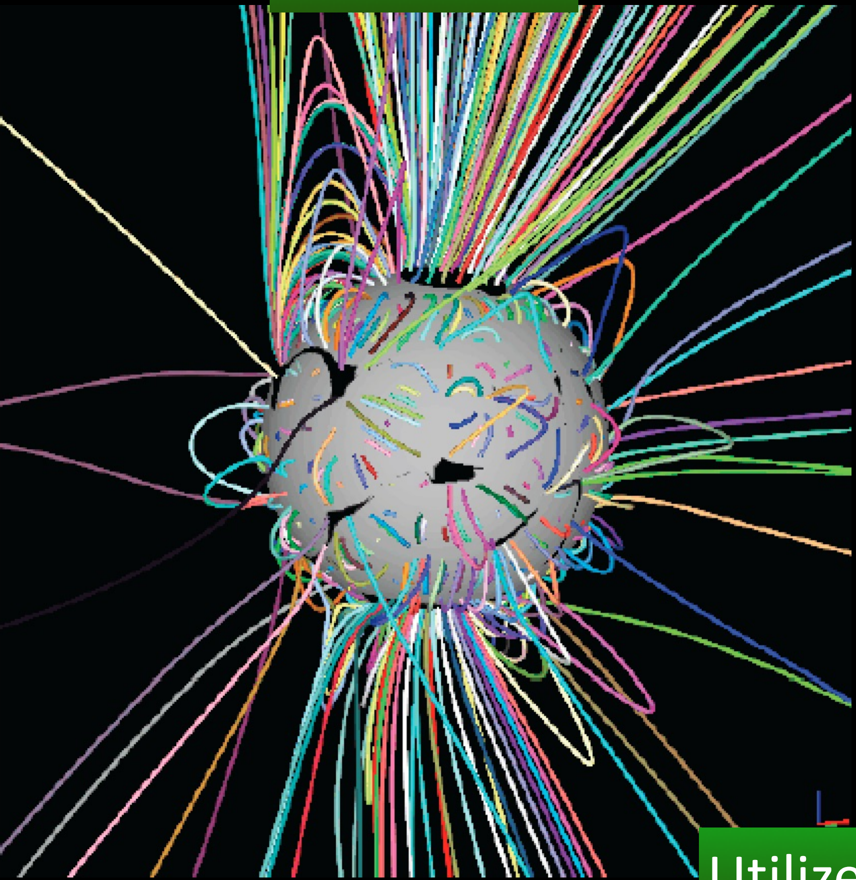


FORWARD SolarSoft IDL package

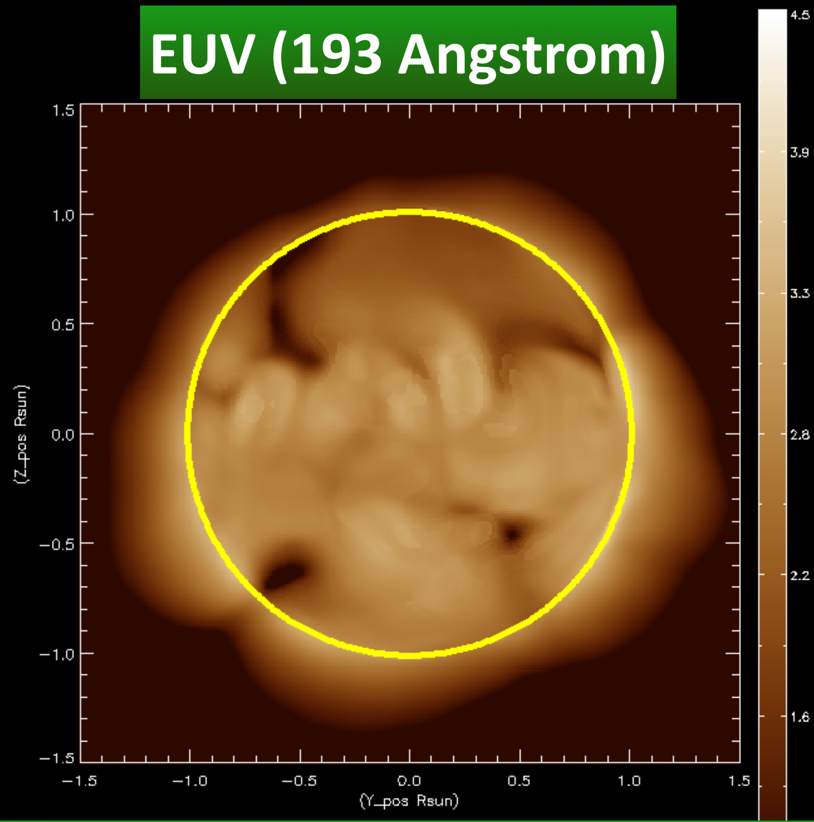
Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS



EUV (193 Angstrom)



Utilizes CHIANTI database for modeling UV/EUV lines

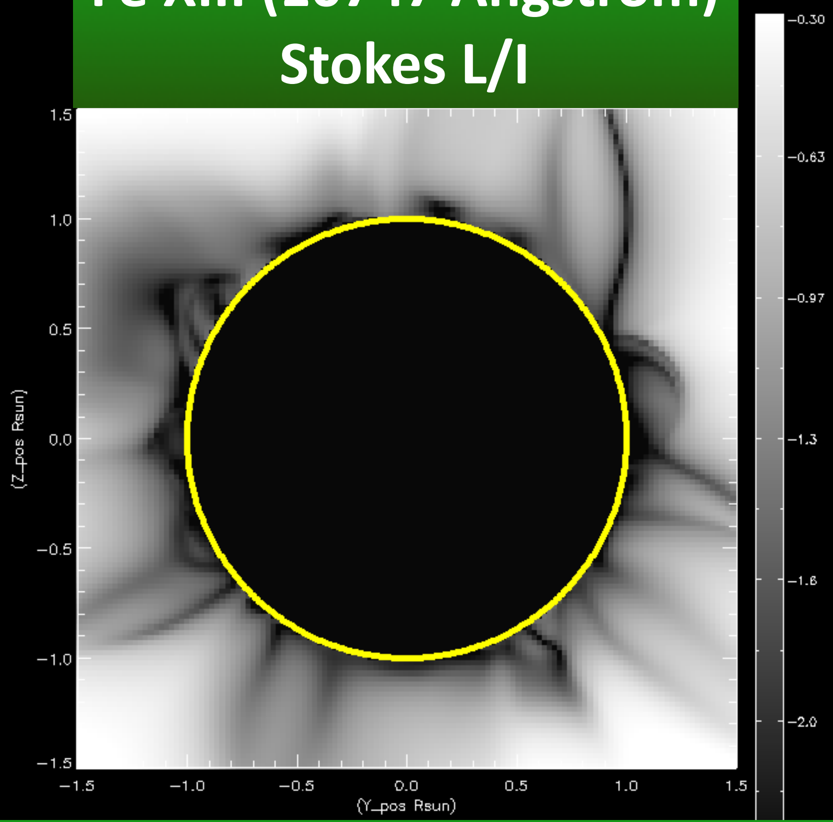
FORWARD SolarSoft IDL package

Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS

Fe XIII (10747 Angstrom) Stokes L/I



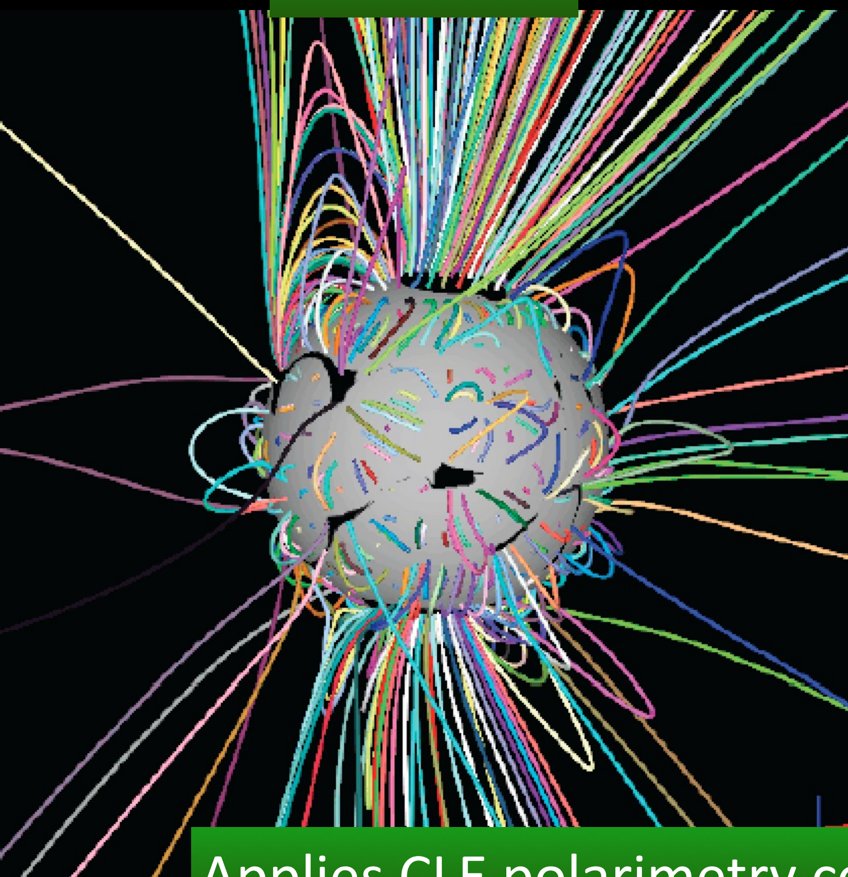
Applies CLE polarimetry code (Judge & Casini) for visible/IR polarimetry

FORWARD SolarSoft IDL package

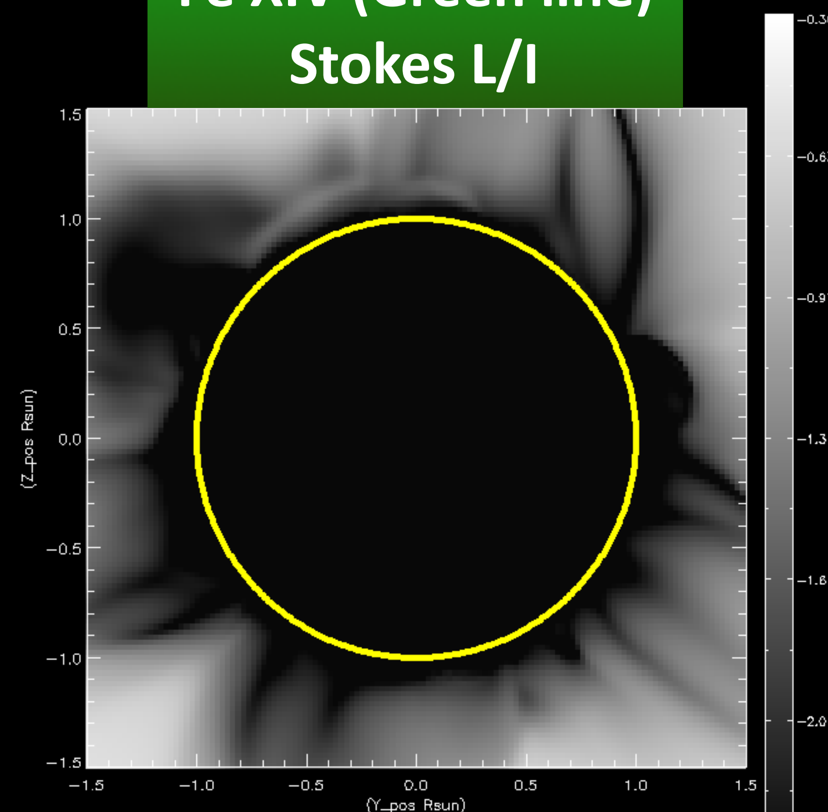
Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS



Fe XIV (Green line)
Stokes L/I



Applies CLE polarimetry code (Judge & Casini) for visible/IR polarimetry

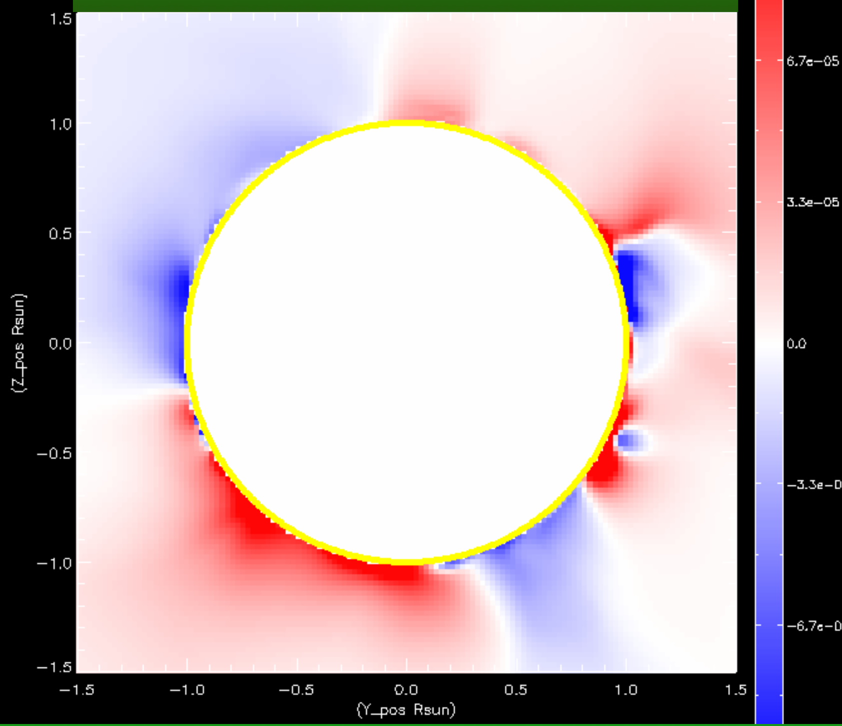
FORWARD SolarSoft IDL package

Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS

Fe XIII (10747 Angstrom) Stokes V/I



Applies CLE polarimetry code (Judge & Casini) for visible/IR polarimetry

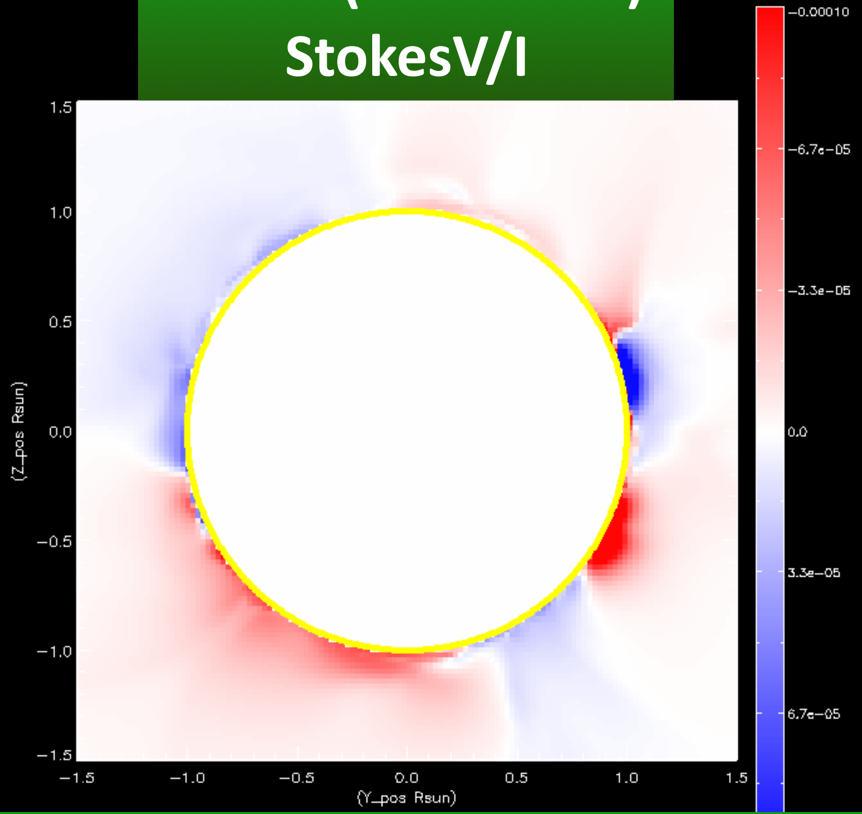
FORWARD SolarSoft IDL package

Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS

Fe XIV (Green line) StokesV/I



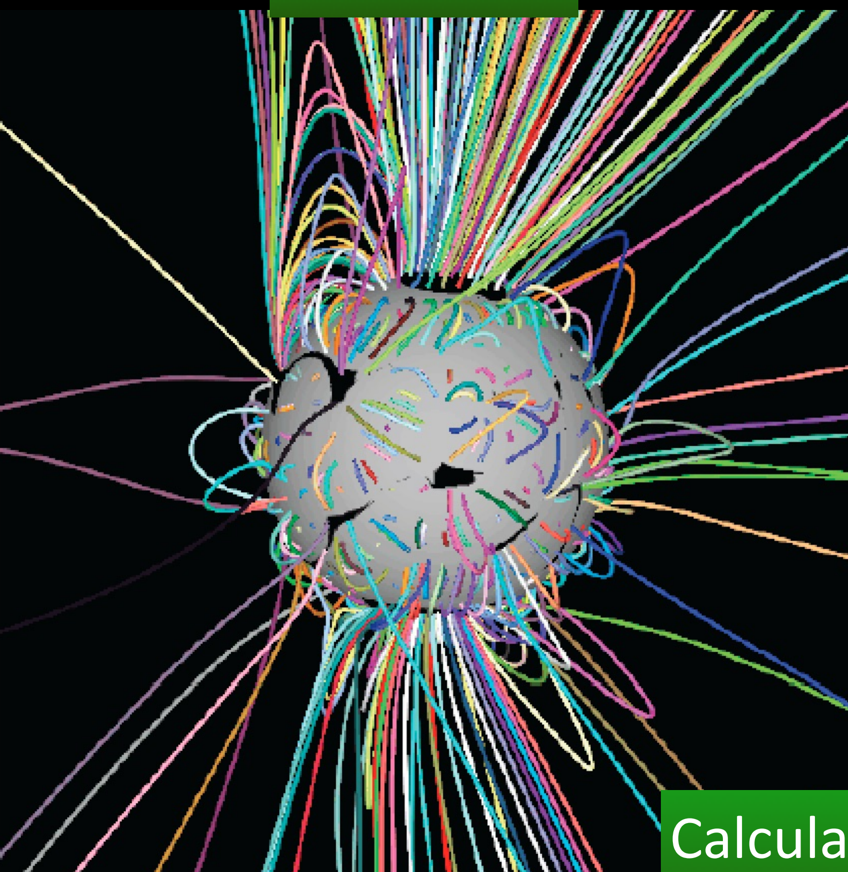
Applies CLE polarimetry code (Judge & Casini) for visible/IR polarimetry

FORWARD SolarSoft IDL package

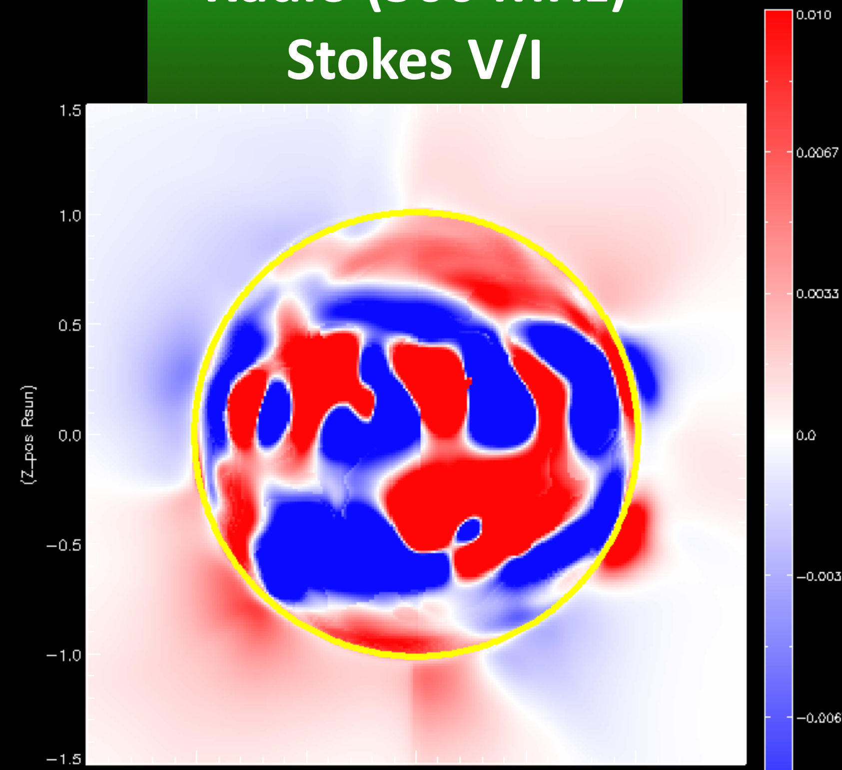
Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS



Radio (500 MHz) Stokes V/I



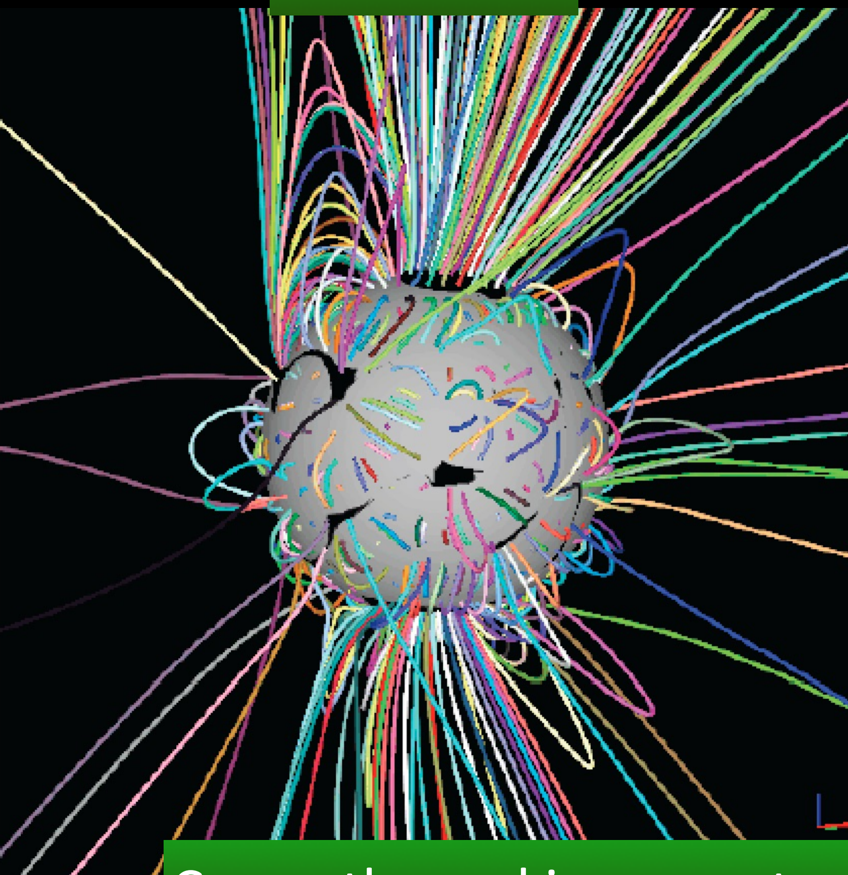
Calculates Bremsstrahlung and gyro resonant emission (codes developed by S. White, T. Bastian)

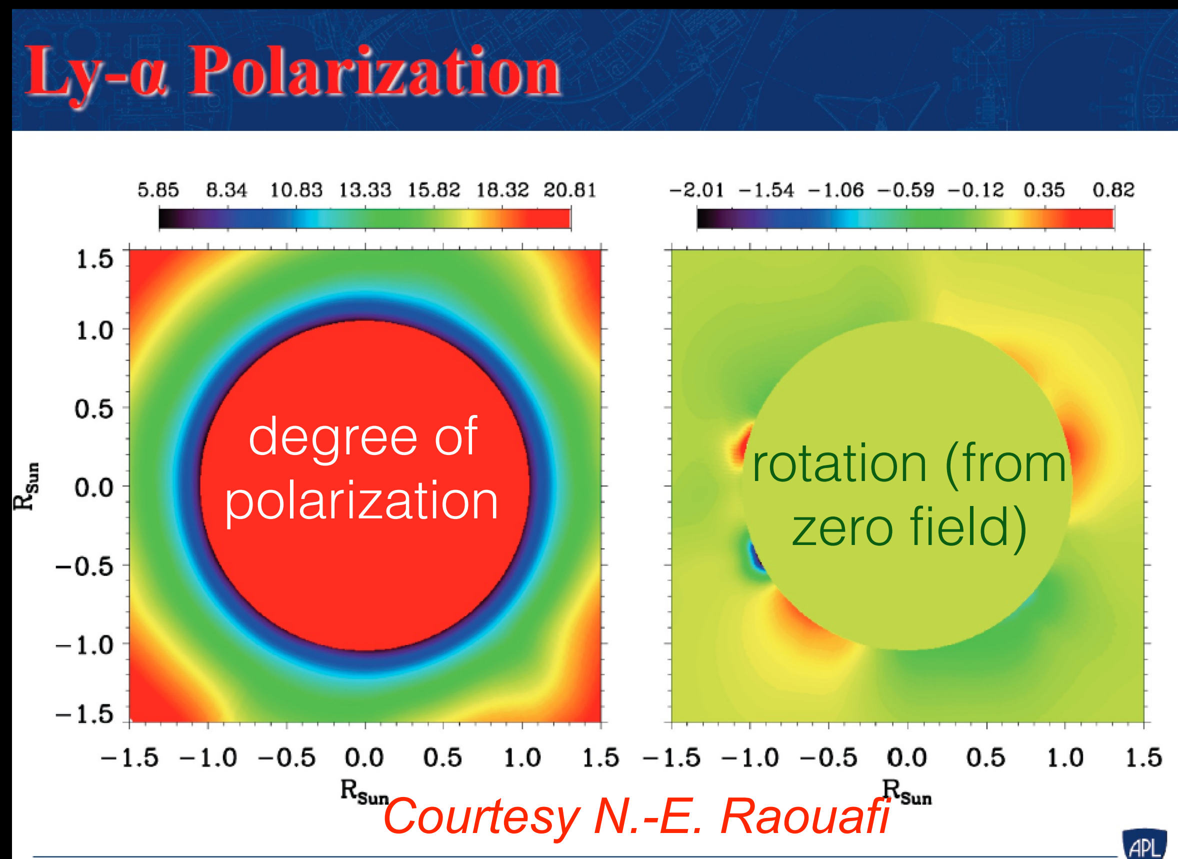
FORWARD SolarSoft IDL package

Given a distribution of plasma and magnetic fields along the line of sight, synthesizes observables from radio to SXR wavelengths.

Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

PSI MAS

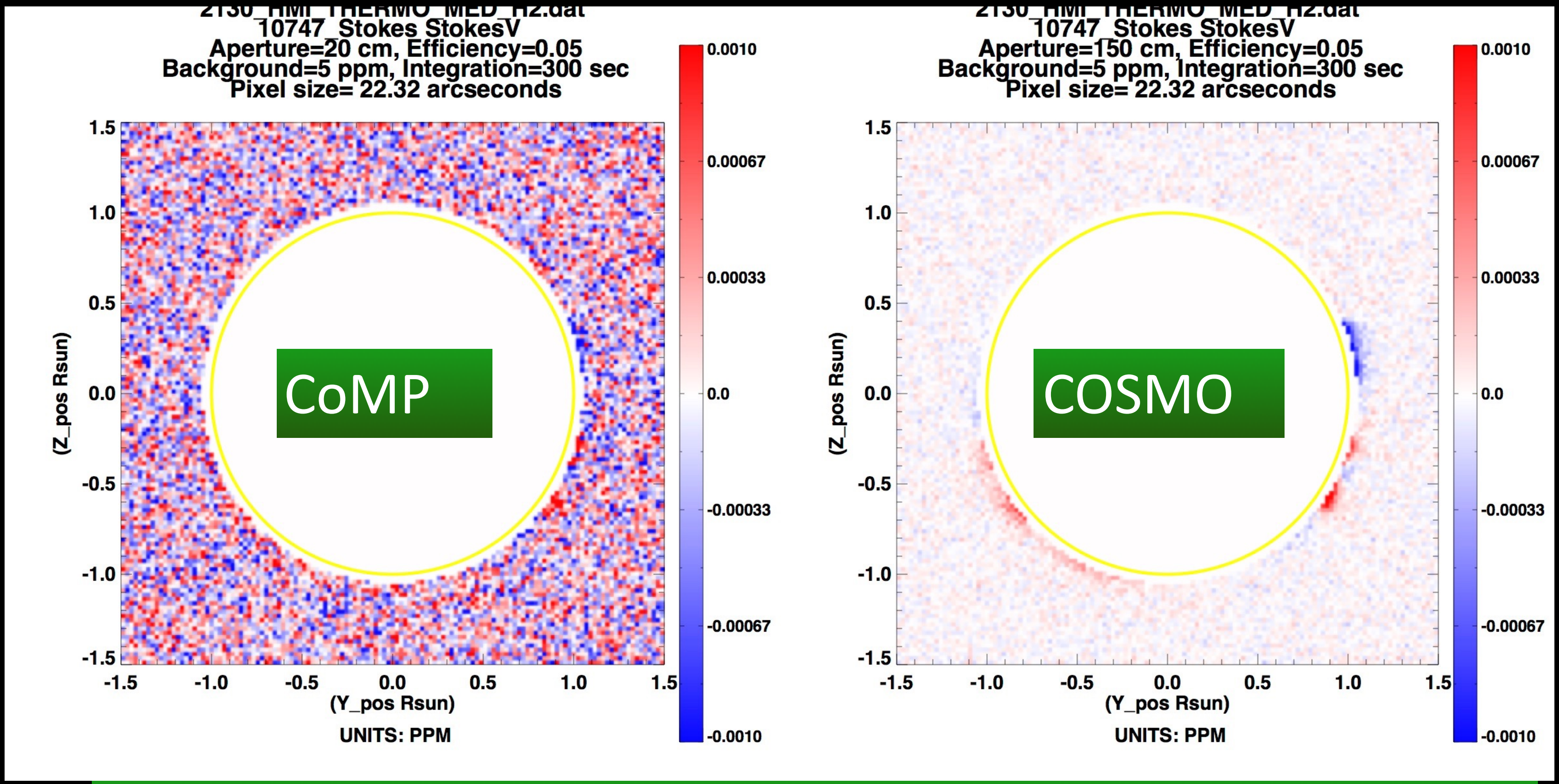




Currently working on extension to unsaturated Hanle regime!

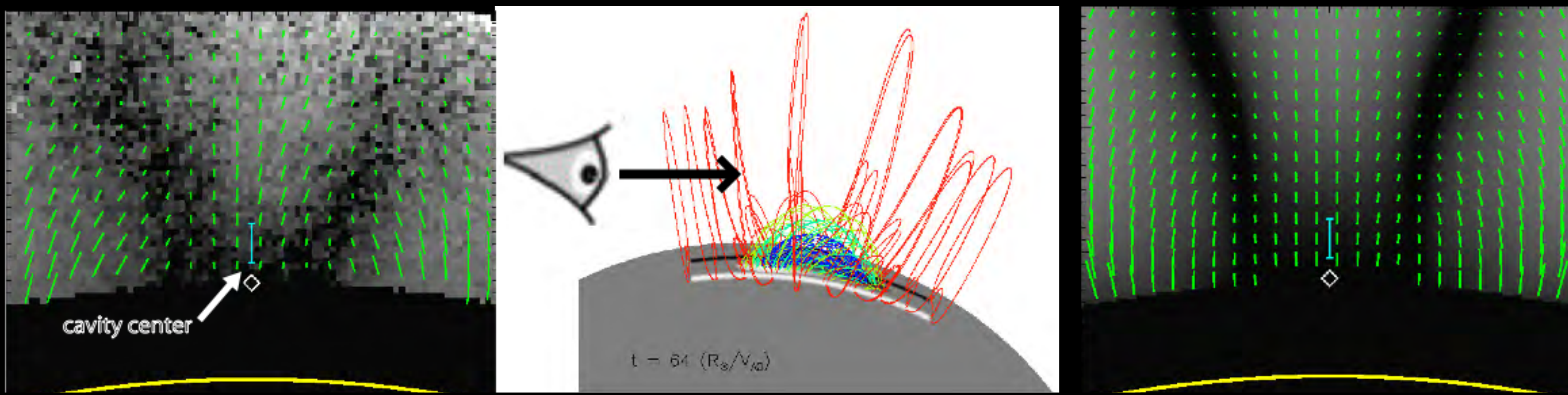
FORWARD SolarSoft IDL package

Can include photon noise



5 minute integration of circular polarization for Fe XIII

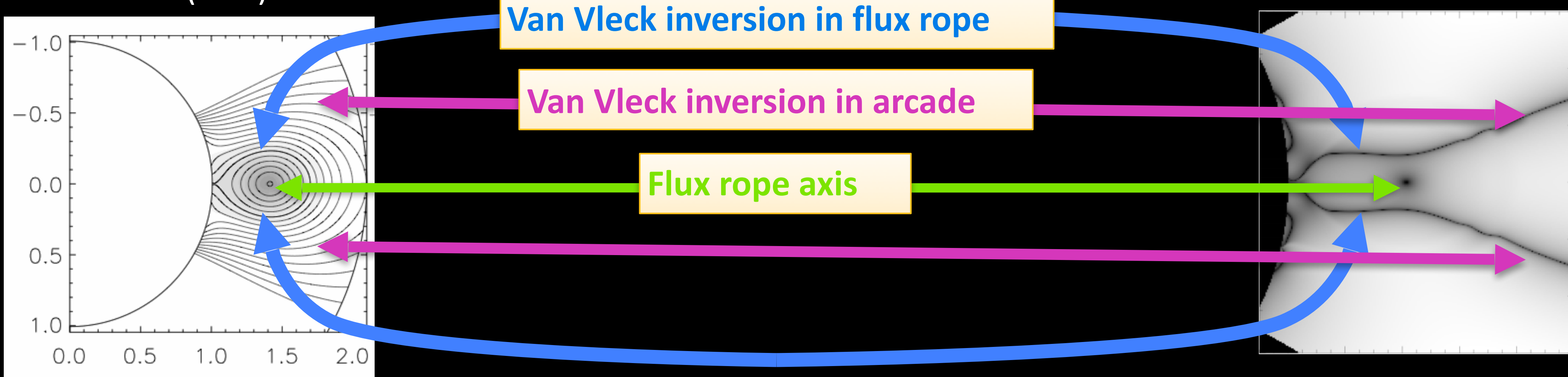
FORWARD SolarSoft IDL package



Demonstrated diagnostic capability

Model B (POS)

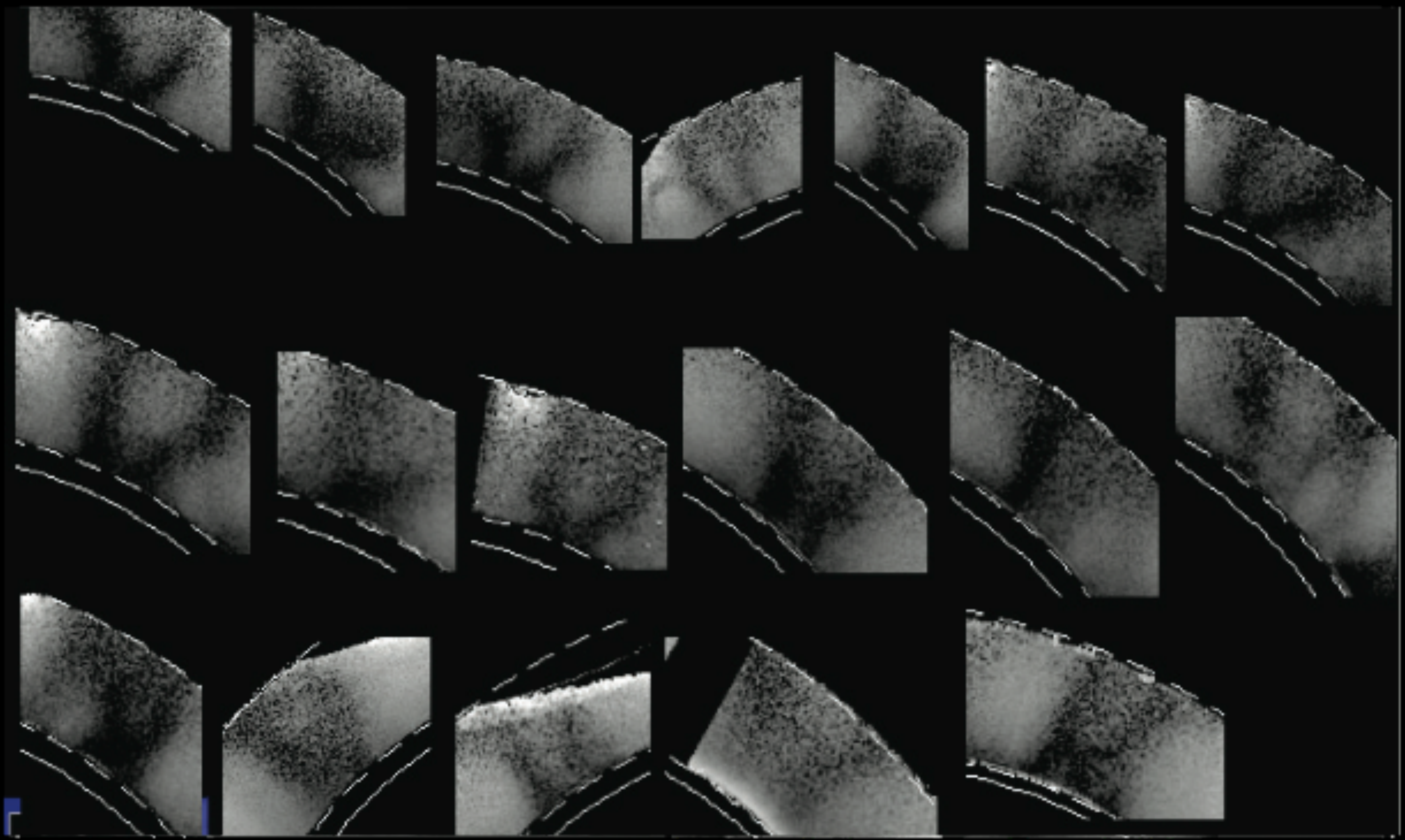
Model L/I (POS)



Bak-Steslicka et al., 2013

FORWARD SolarSoft IDL package

Coronal cavities = magnetic flux ropes



Gibson, 2014

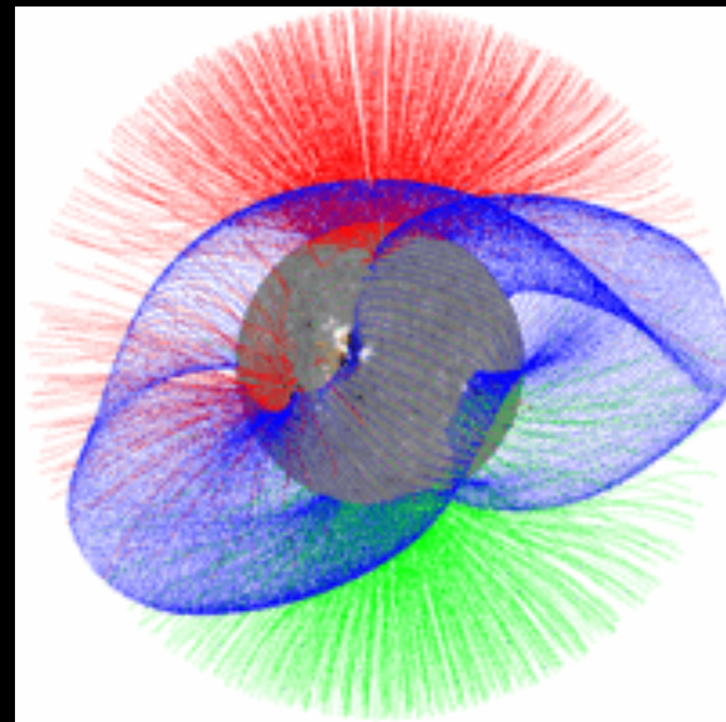
But how do we quantify the magnetic field?

DOC-FM

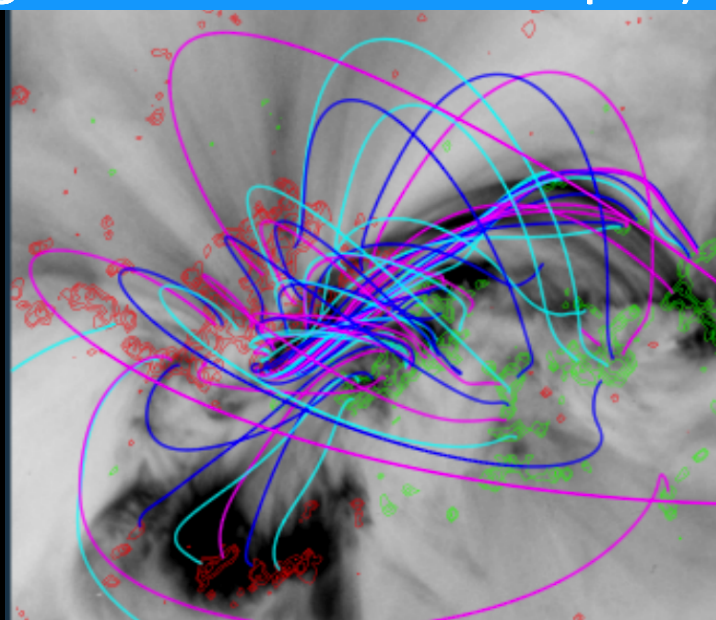
Data-optimized coronal field model (DOC-FM)

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

Initial guess global magnetic field

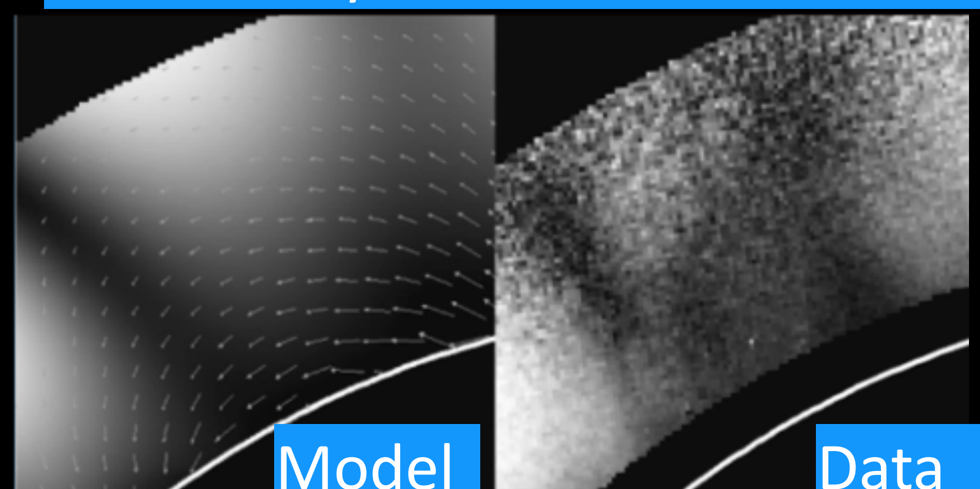


Solve for best fit parameters (location, orientation, strength, height of inserted flux ropes).



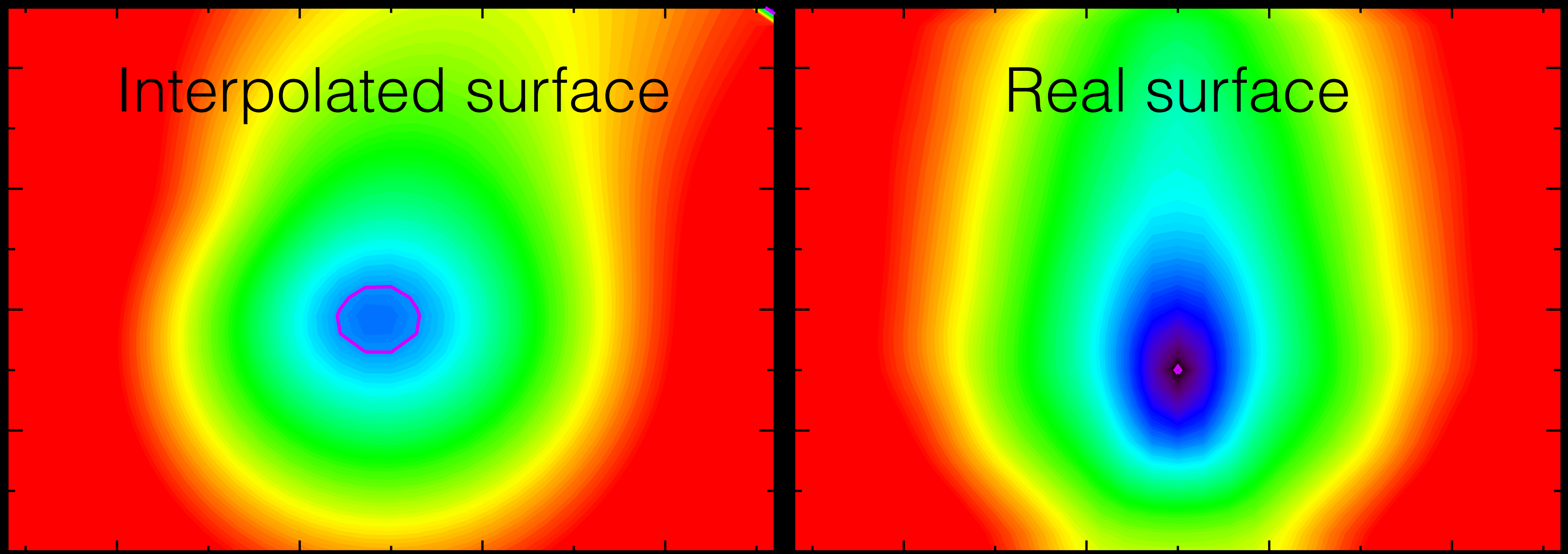
Add currents (flux-rope insertion) where synthetic observations don’t match data

Generate synthetic observables



Data-optimized coronal field model (DOC-FM)

Optimization methods (HAO-CISL collaboration)

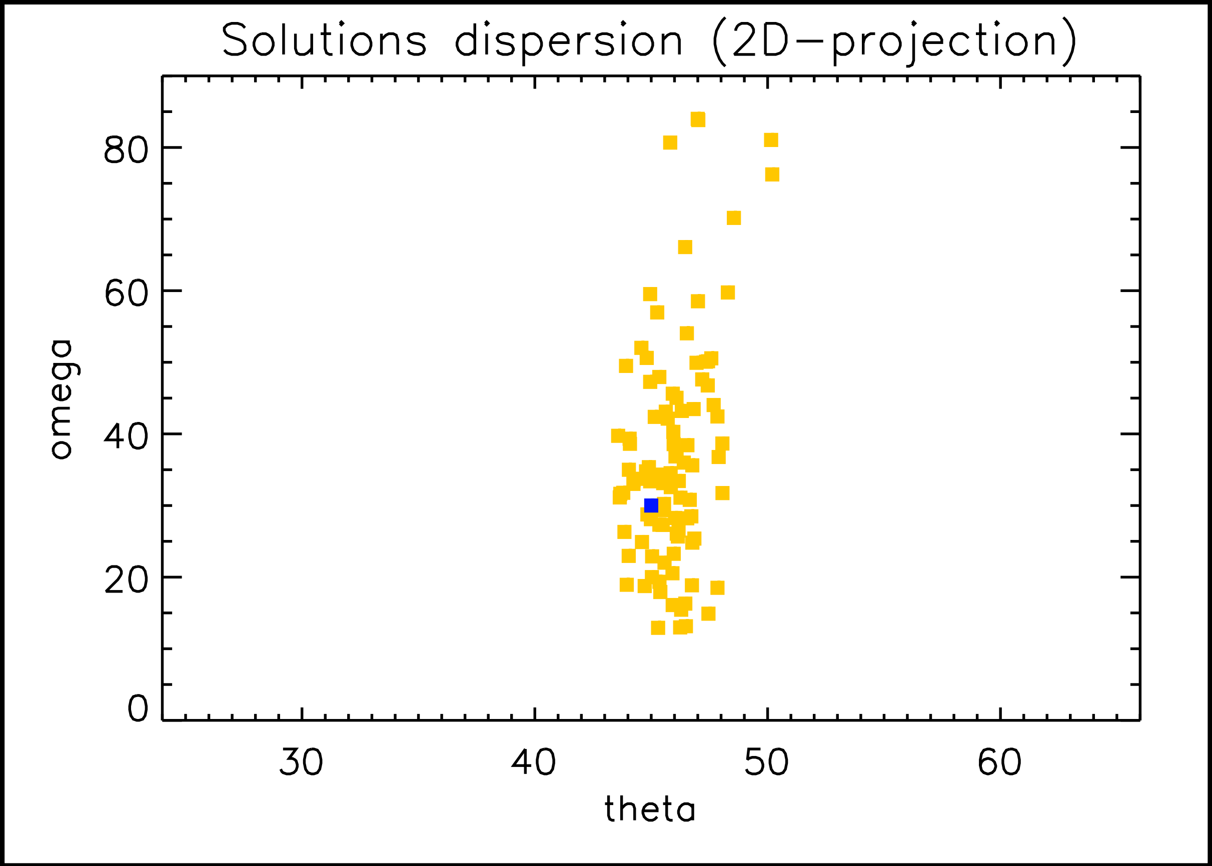


- Three-parameter fit for flux rope model, using I, Q, U, V synthetic data
- Sparse sampling of parameter space (Latin Hypercube); from $n^p = 31^3$ to n = 31 points
- Chi-squared-type metric shown as interpolated surface of hypercube (left) vs. fully resolved metric surface (right)

Dalmasse et al., in preparation, 2015

Data-optimized coronal field model (DOC-FM)

Optimization methods (HAO-CISL collaboration)

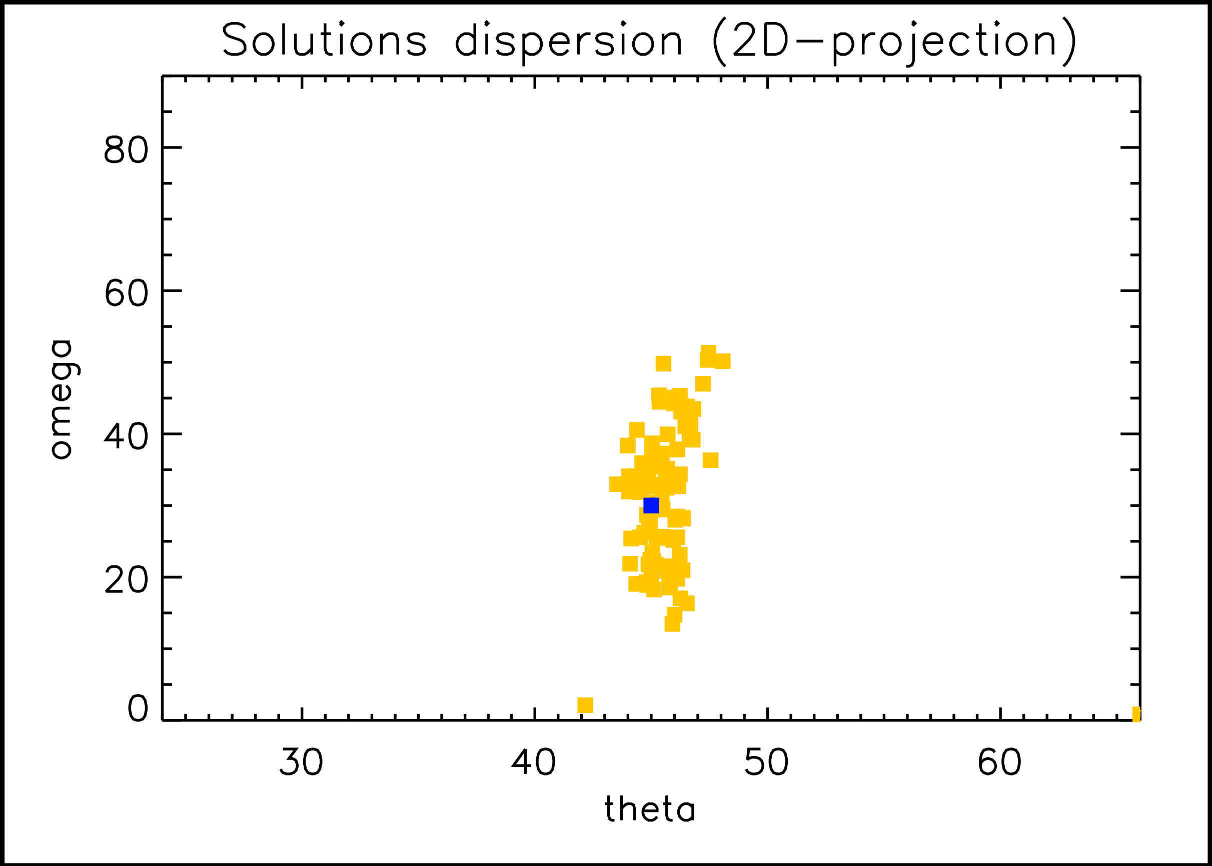


Best fit parameter dispersion for 100 realizations of **31**-point sampling

Dalmasse et al., in preparation, 2015

Data-optimized coronal field model (DOC-FM)

Optimization methods (HAO-CISL collaboration)

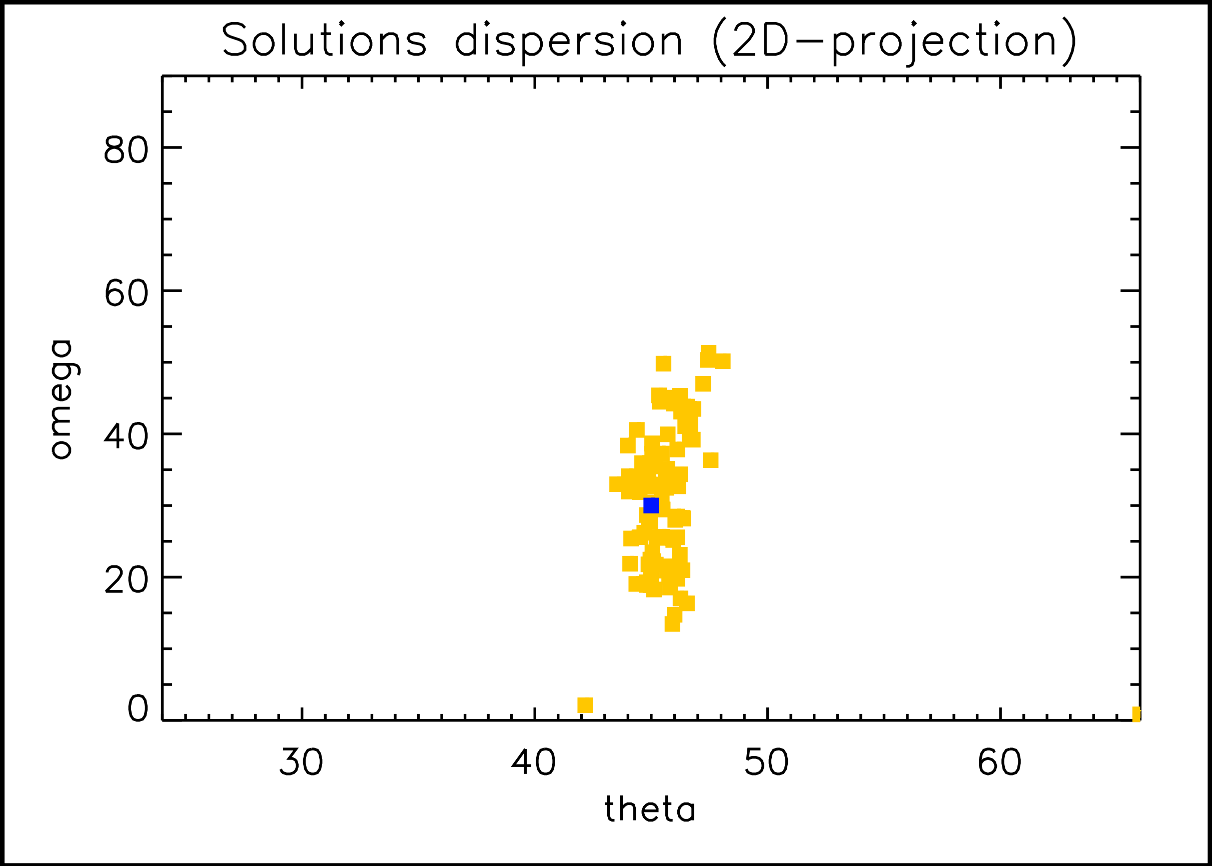


Best fit parameter dispersion for 100 realizations of **93**-point sampling

Dalmasse et al., in preparation, 2015

Data-optimized coronal field model (DOC-FM)

Optimization methods (HAO-CISL collaboration)



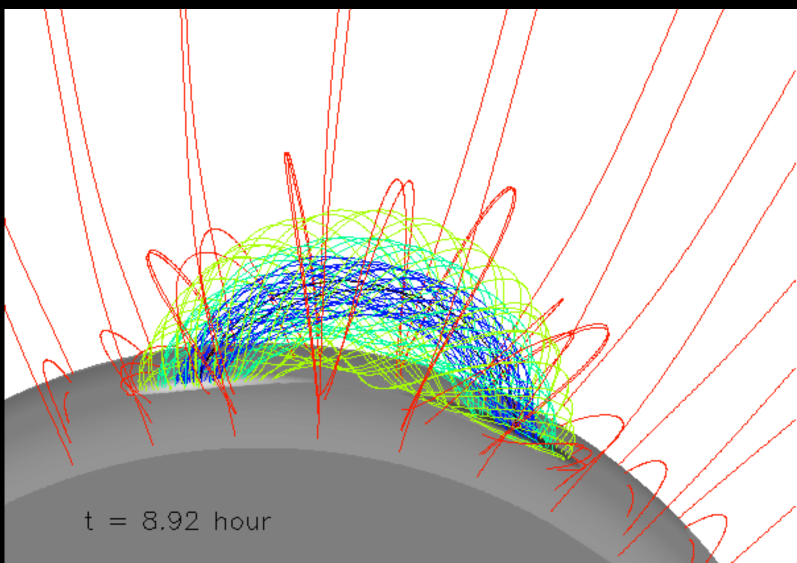
Work in progress: further increasing hypercube size, analyzing errors, and optimizing choices of observables and related metrics

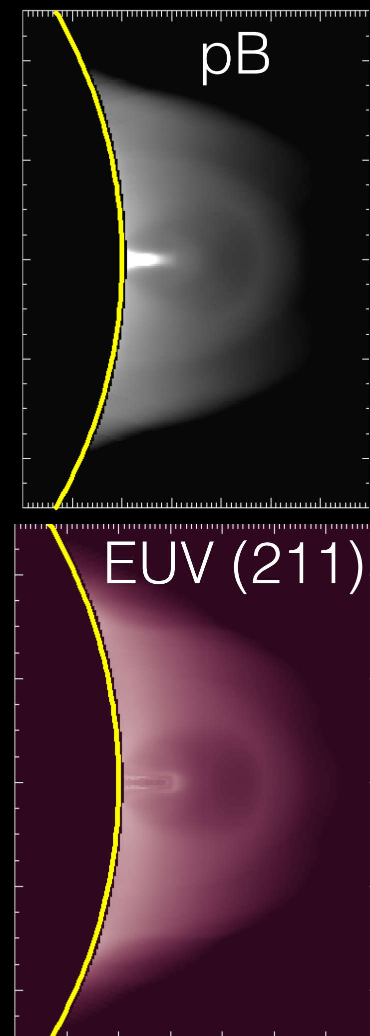
Dalmasse et al., in preparation, 2015

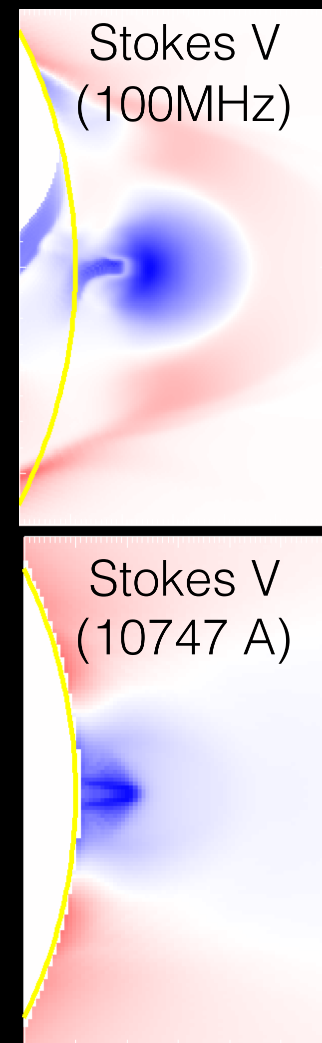
Future plans: Synthetic test-beds

Use to test diagnostic methods (like DOC-FM):

- 3D representations of plasma and magnetic field (ground truth)
- forward-modeled multi-wavelength observables





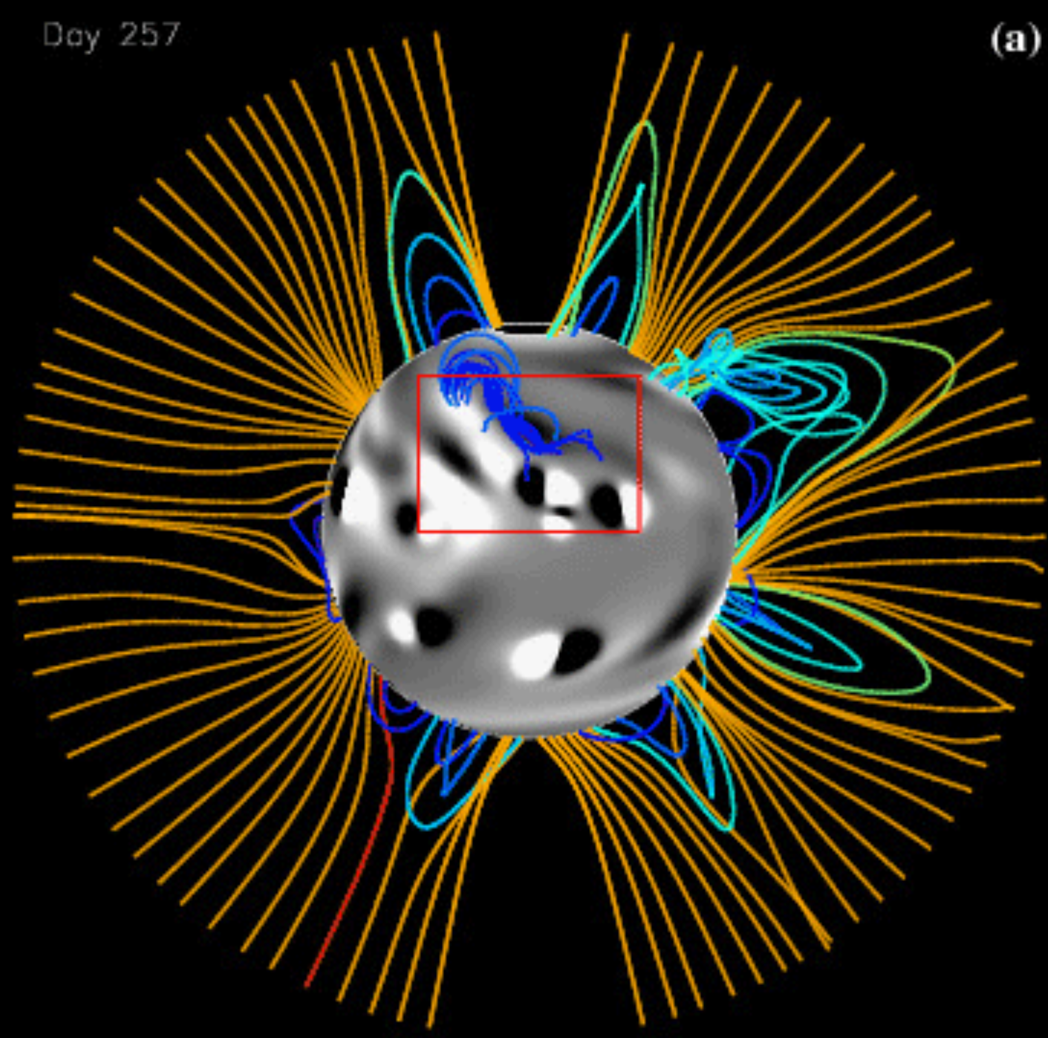


Quiescent filament flux rope with thermodynamics — Fan

Future plans: Synthetic test-beds

Use to test diagnostic methods (like DOC-FM):

- 3D representations of plasma and magnetic field (ground truth)
- forward-modeled multi-wavelength observables

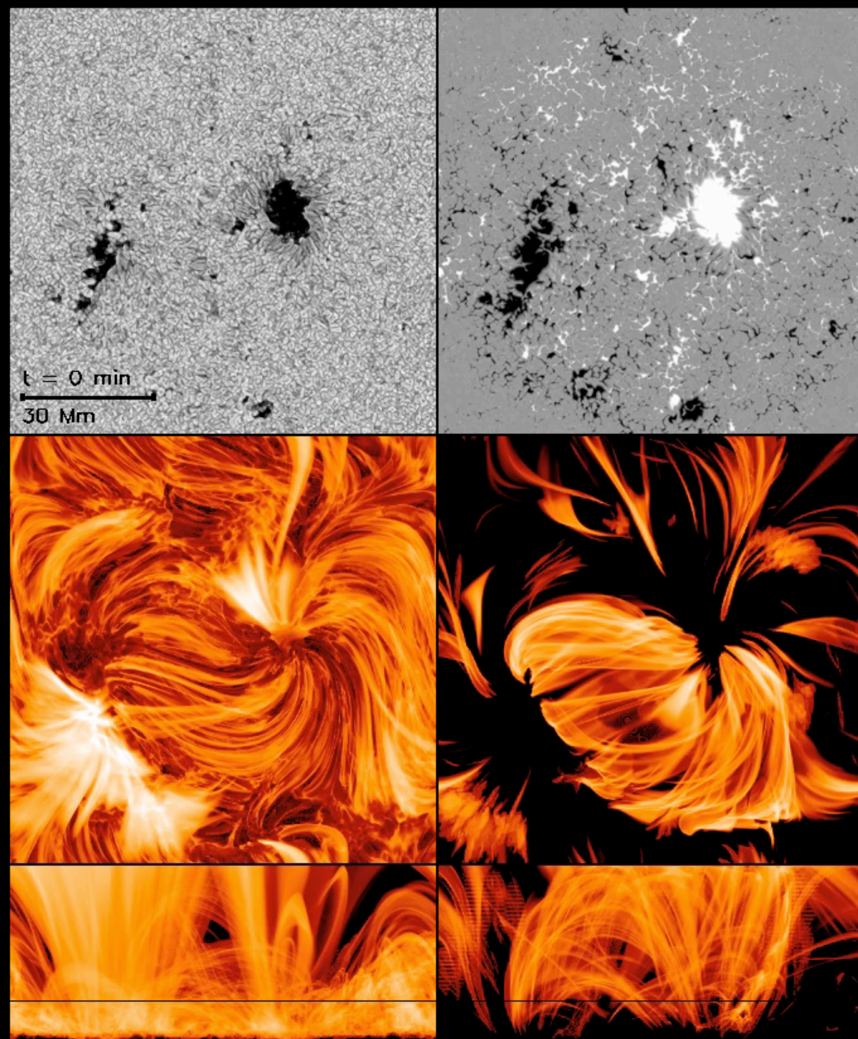


Global model — Mackay/Yeates (with plasma — Dalmasse)

Future plans: Synthetic test-beds

Use to test diagnostic methods (like DOC-FM):

- 3D representations of plasma and magnetic field (ground truth)
- forward-modeled multi-wavelength observables



Active Region simulation — Rempel

Conclusions

Coronal **magnetism matters** for space weather

A range of observations yield clues to the coronal field; **Polarimetric data** provide the most direct information.

Actually **quantifying the 3D global field** from these data is not easy.

DOC-FM: MHD-model based approach to **forward-fitting the global field**

Synthetic testbeds allow us (and others!) to develop and refine an inversion framework, and in the process, to establish the best observations, models and optimization methods

Our ultimate goal: **improved B_z forecast**