Modeling the solar corona with FORWARD

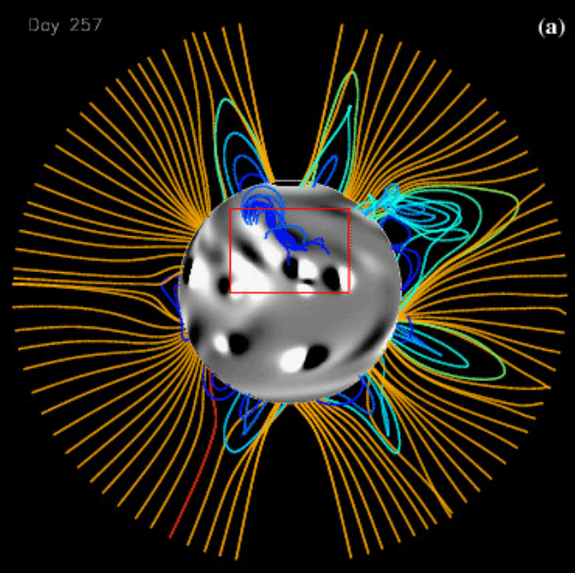
Sarah Gibson

https://www2.hao.ucar.edu/modeling/FORWARD-home

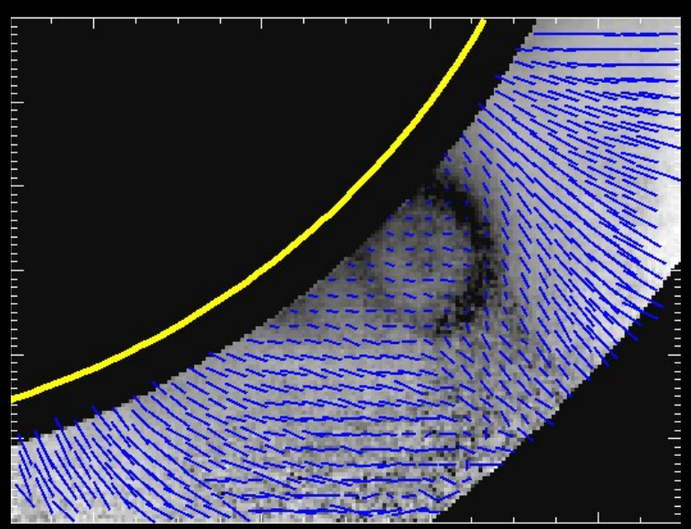
Observations meet models

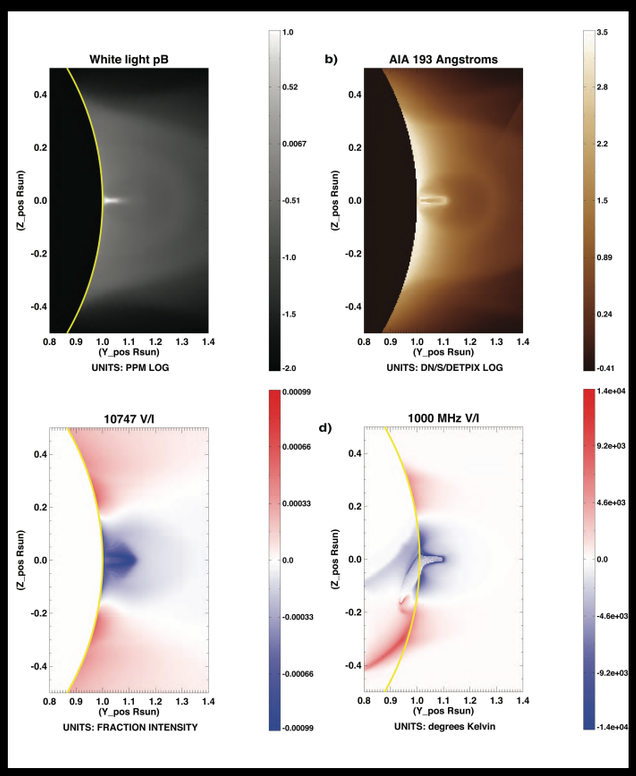
Solving an inverse problem requires three things:

- a means of specifying the **physical state** (e.g., the distribution of density, temperature, velocity, and magnetic field)
- a well-defined forward calculation (i.e., the **physical process** relating the physical state and the observations)
- the **observations** themselves.

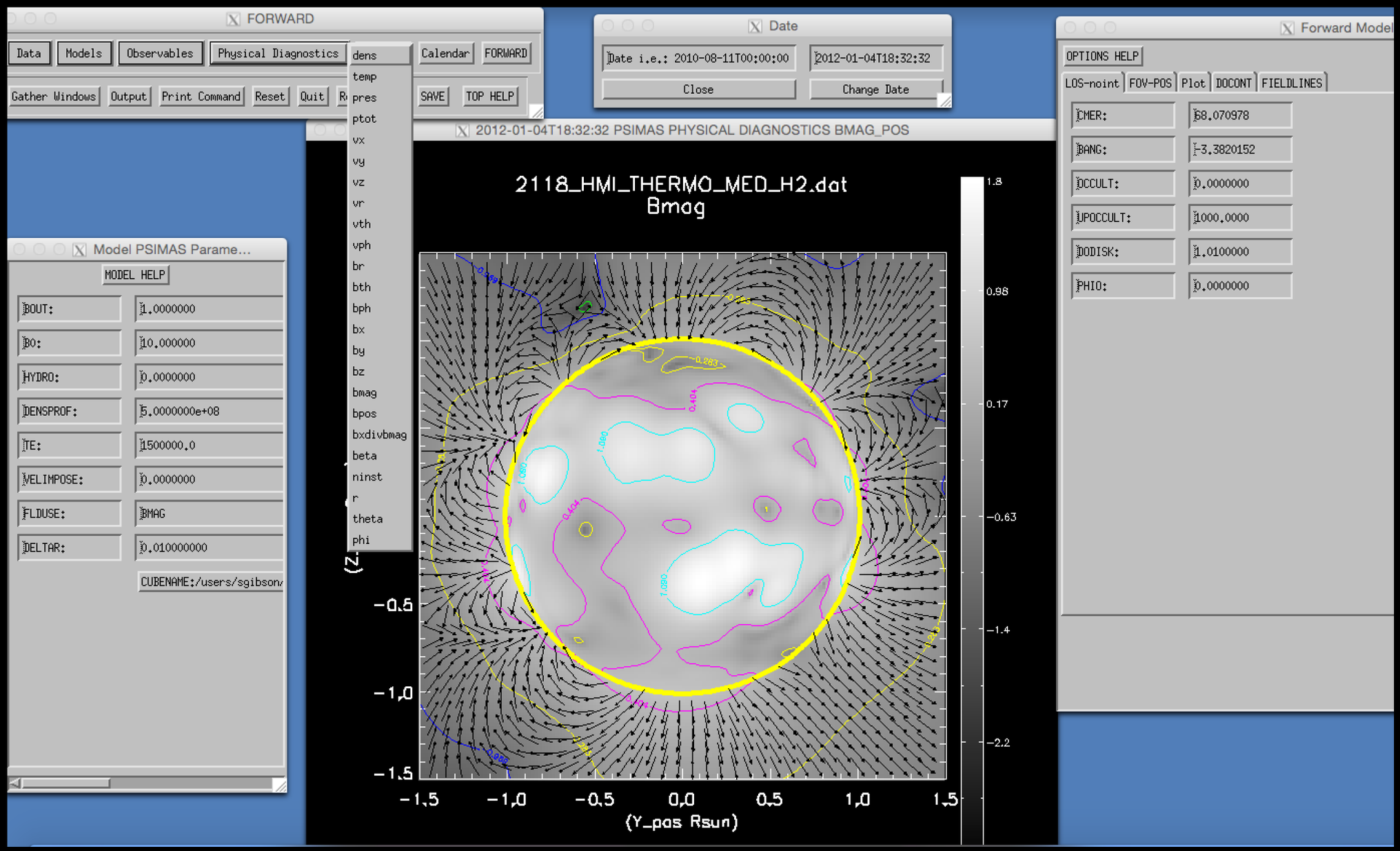


The FORWARD SolarSoft package incorporates all three



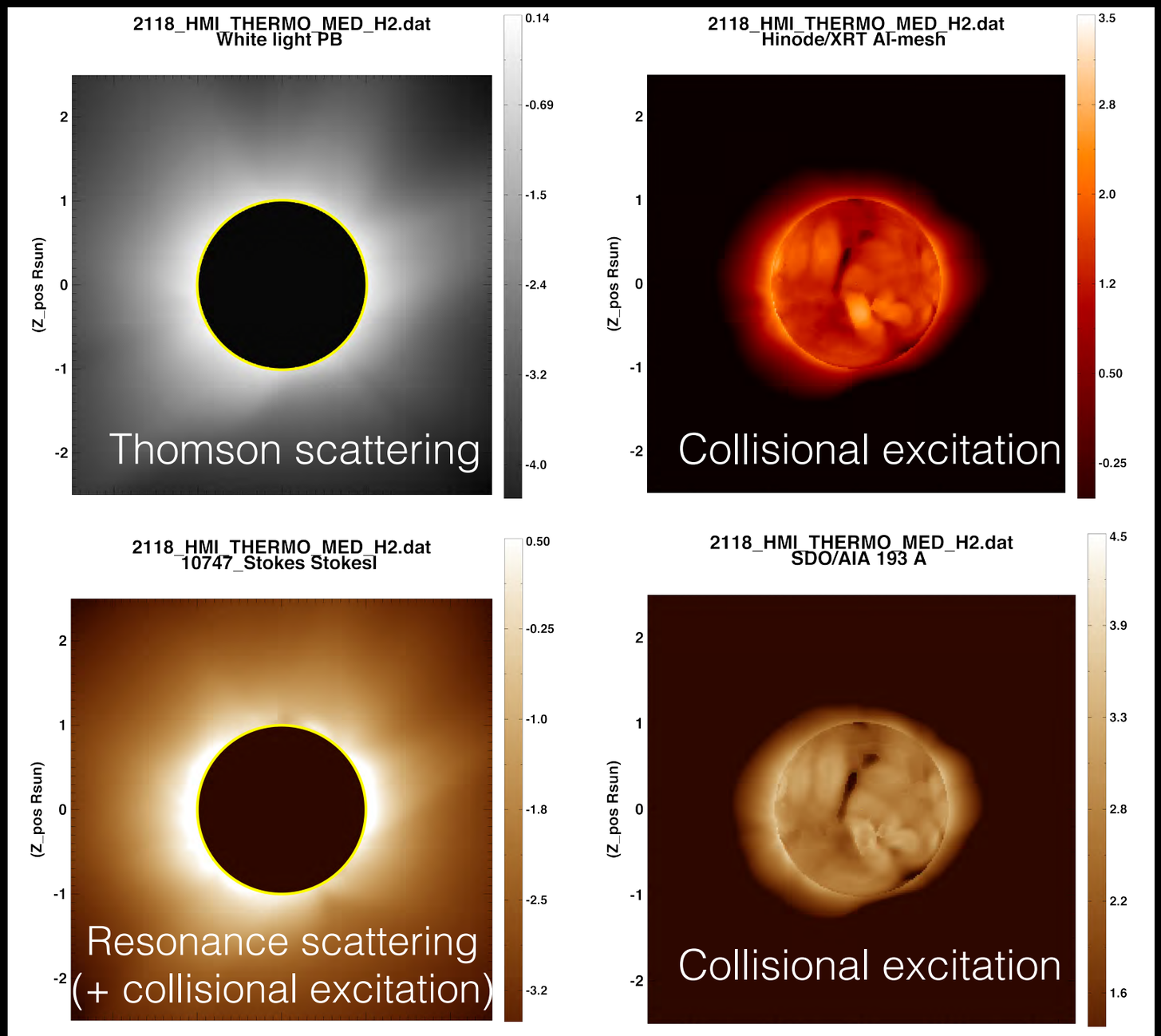


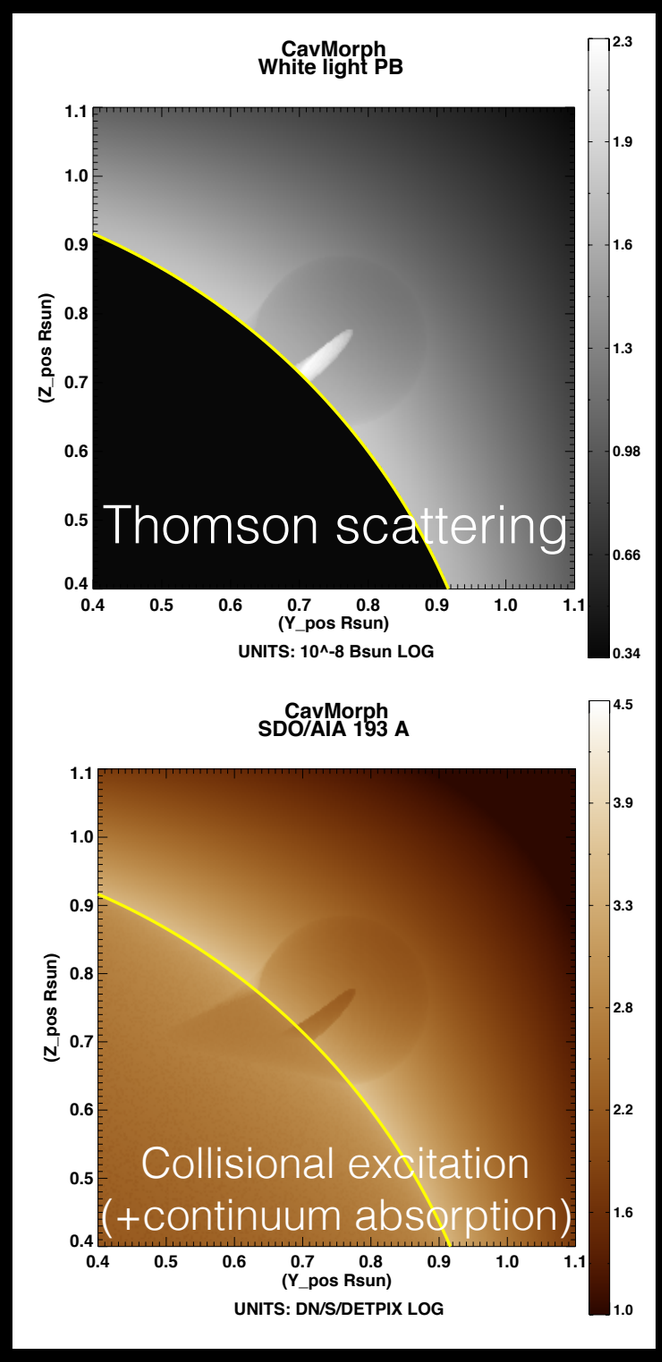
Physical State



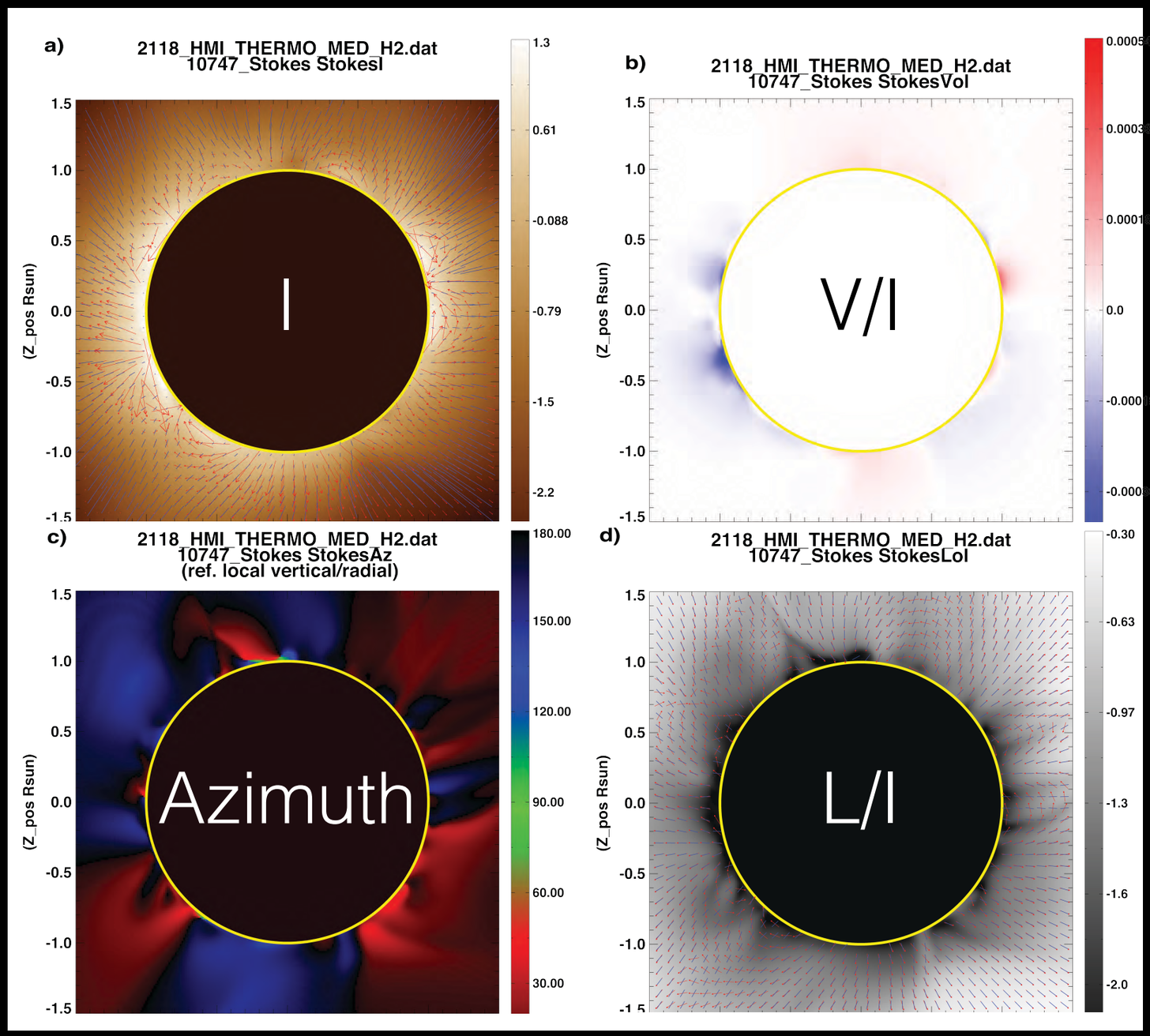
Works with any analytic or numerical model, but automatically interfaces with PFSS extrapolation and PSI MAS MHD simulation (given date)

Physical processes



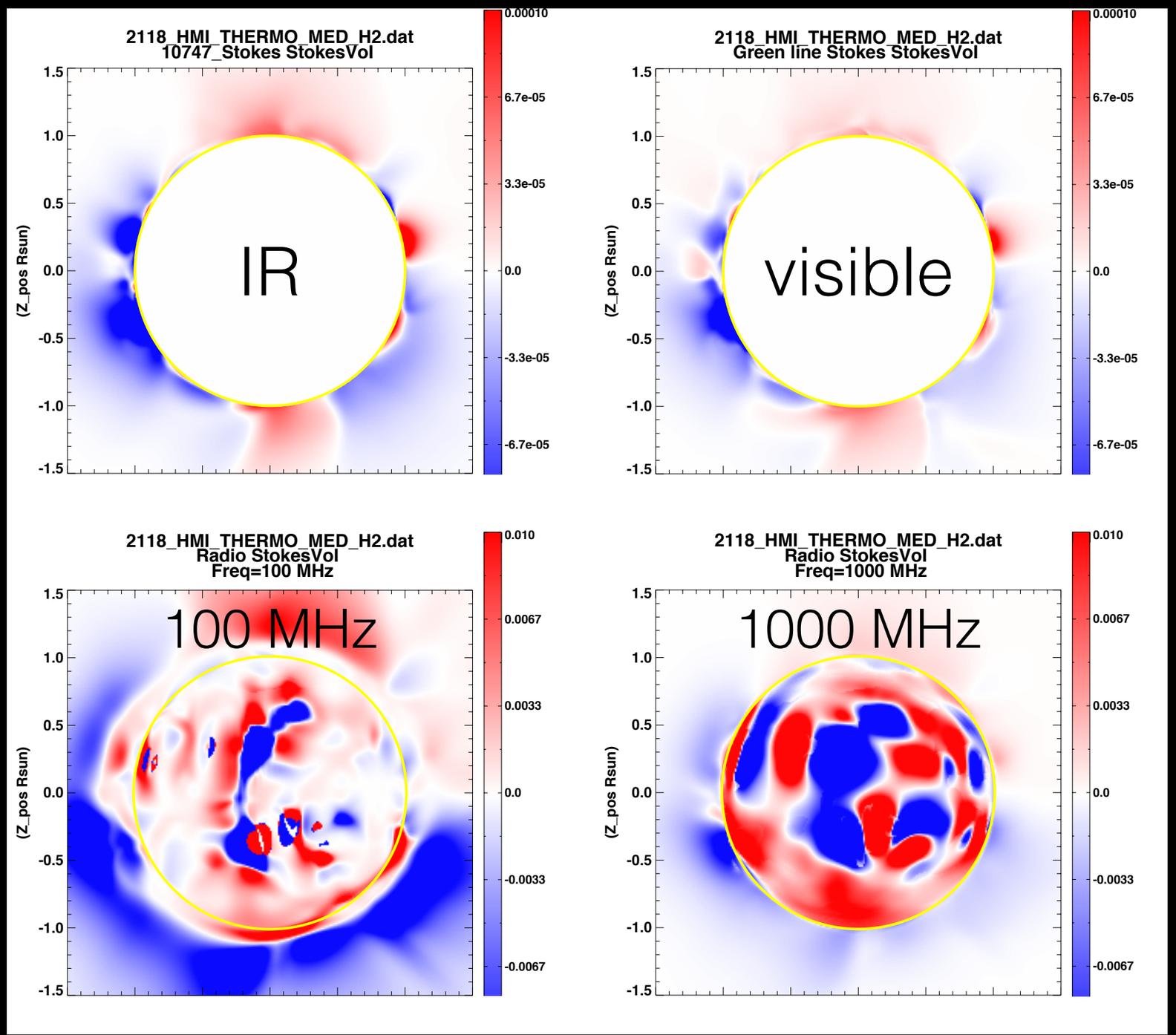


Physical processes



Polarization (Zeeman, saturated Hanle)

Physical processes



Circular polarization at different wavelengths:

different dependencies on plasma along the line of sight

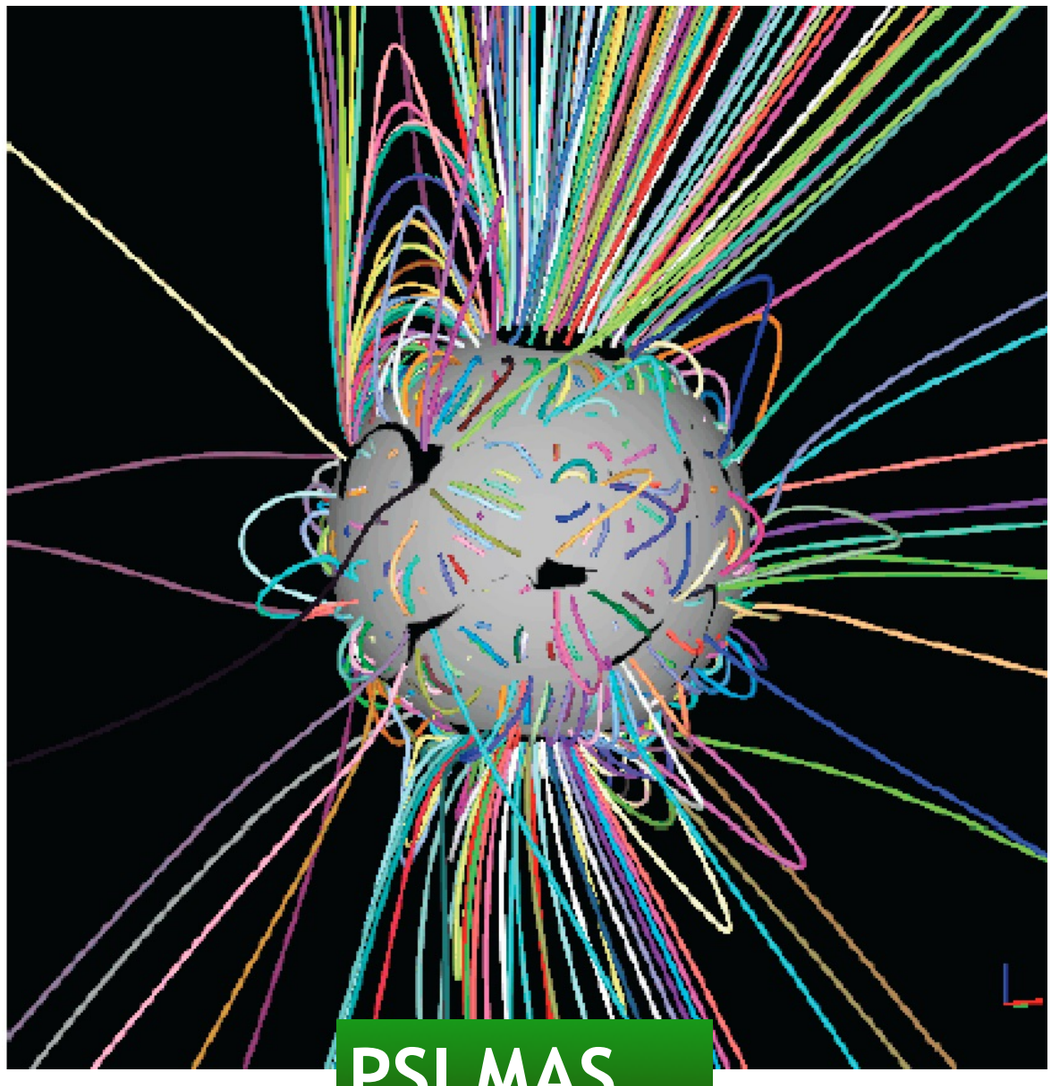
Physical processes

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

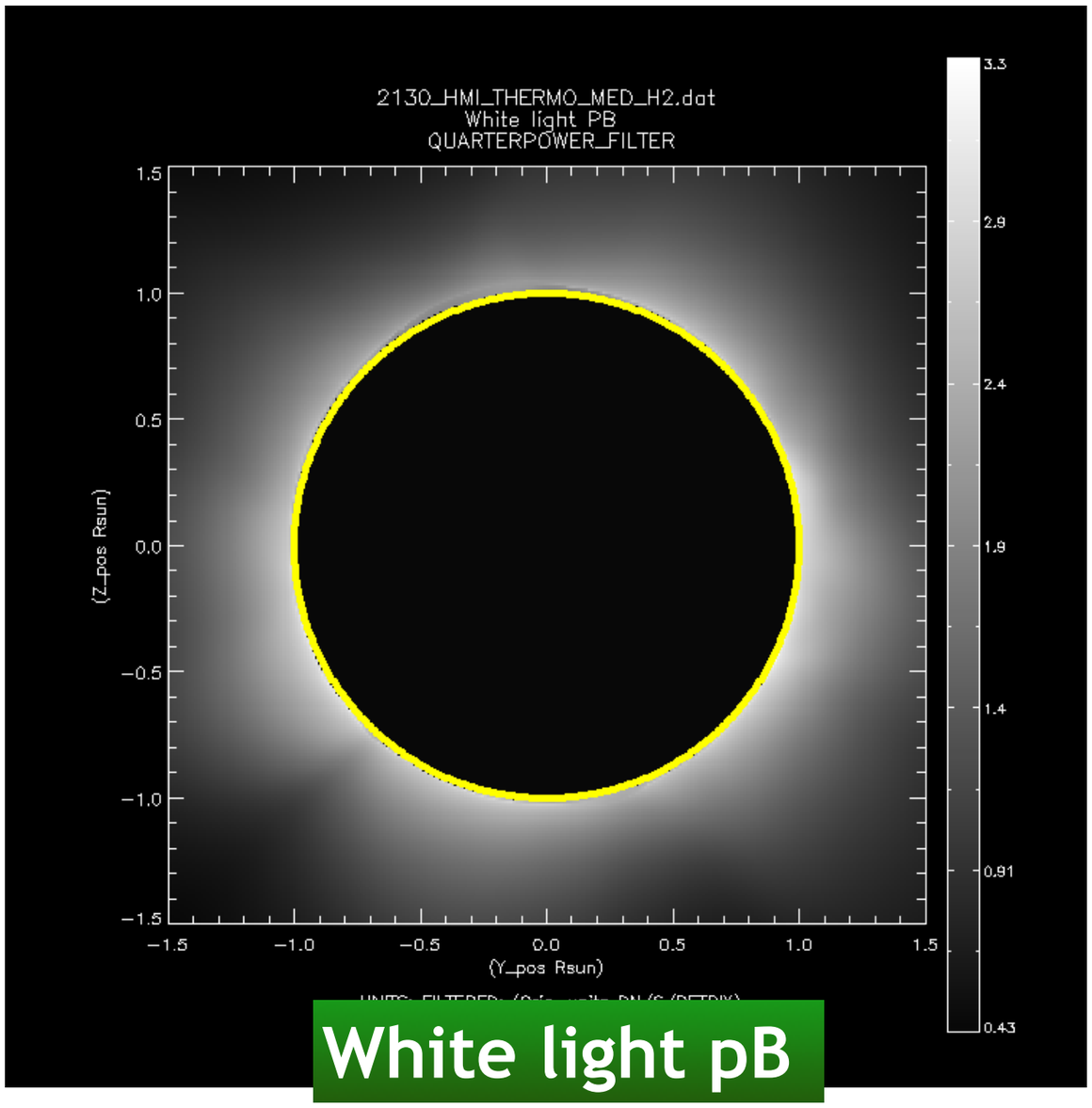
Gibson et al., FRASS, 2016

FORWARD SolarSoft IDL package

- Given plasma/magnetic fields synthesizes multi-λ observables
- Works with any analytic or numerical model
- Applies CLE code of Judge & Casini for visible/IR polarimetry



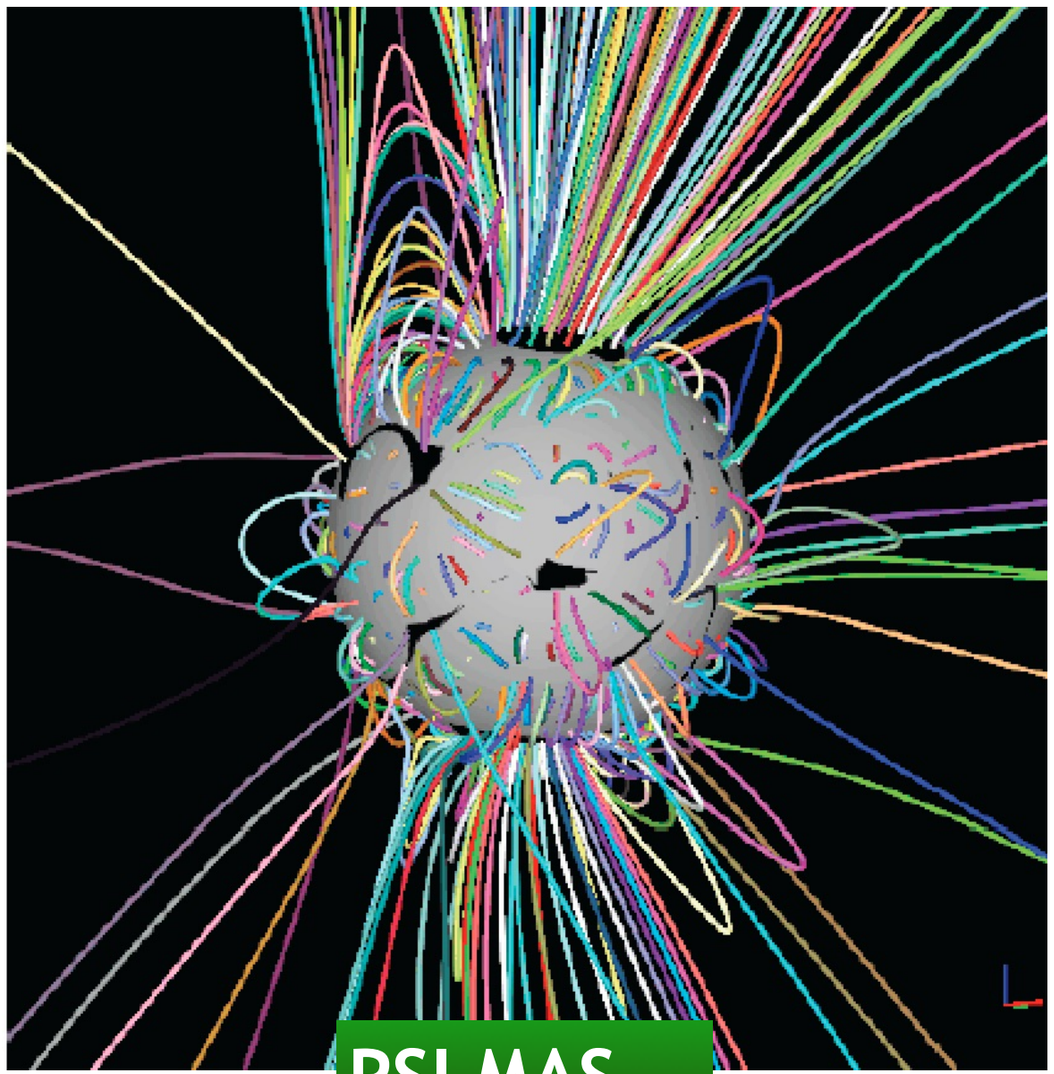
PSI MAS



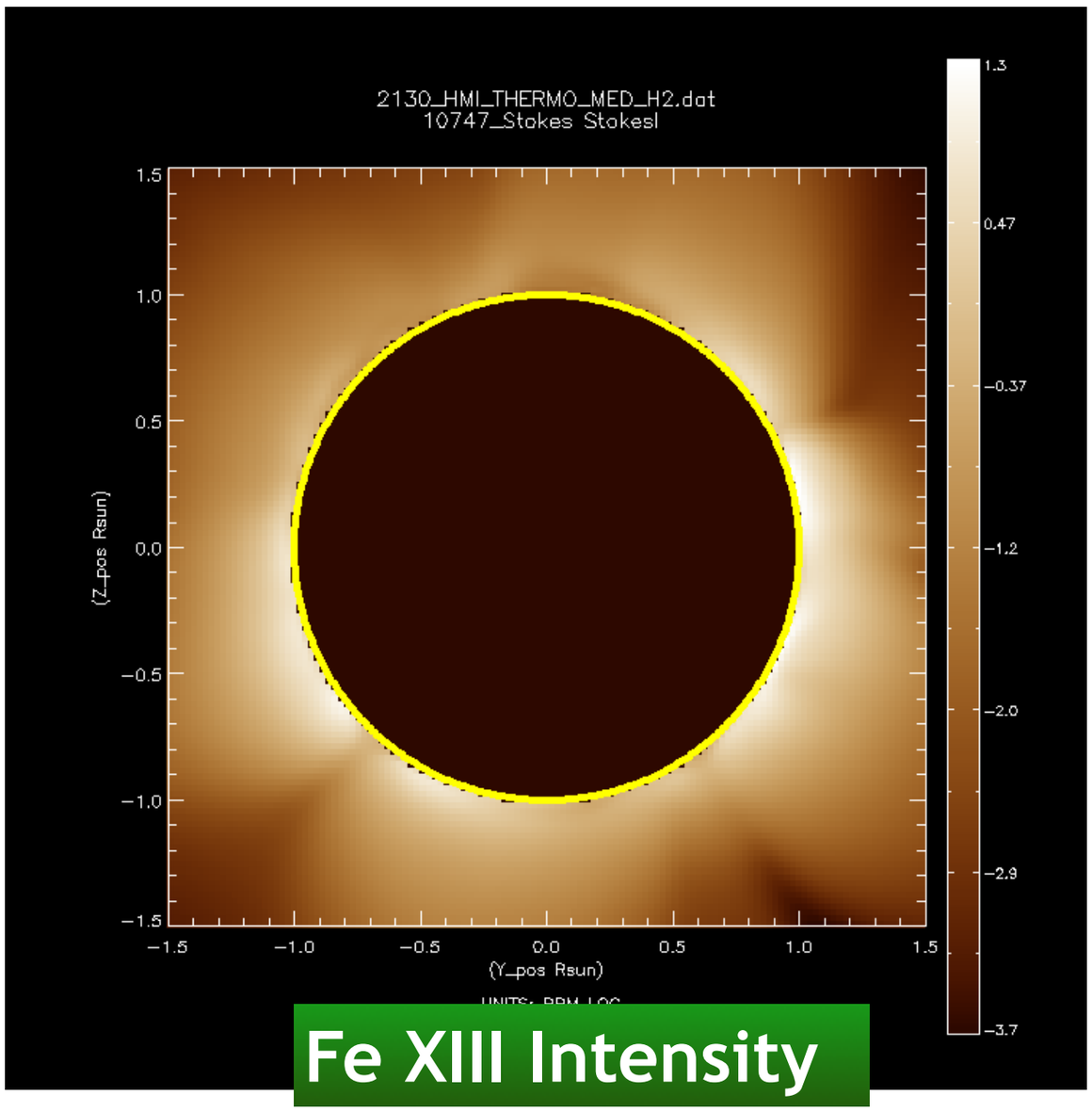
White light pB

FORWARD SolarSoft IDL package

- Given plasma/magnetic fields synthesizes multi-λ observables
- Works with any analytic or numerical model
- Applies CLE code of Judge & Casini for visible/IR polarimetry



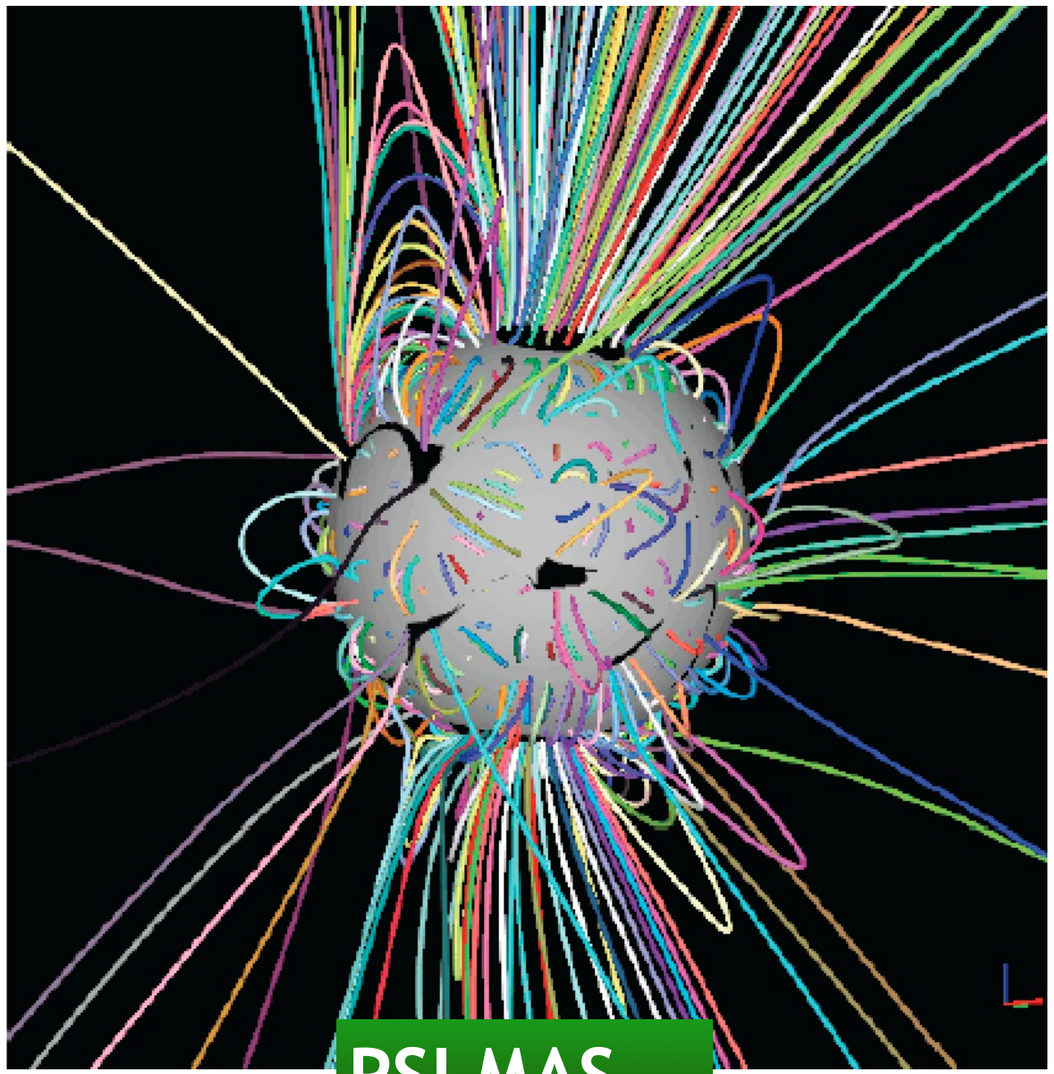
PSI MAS



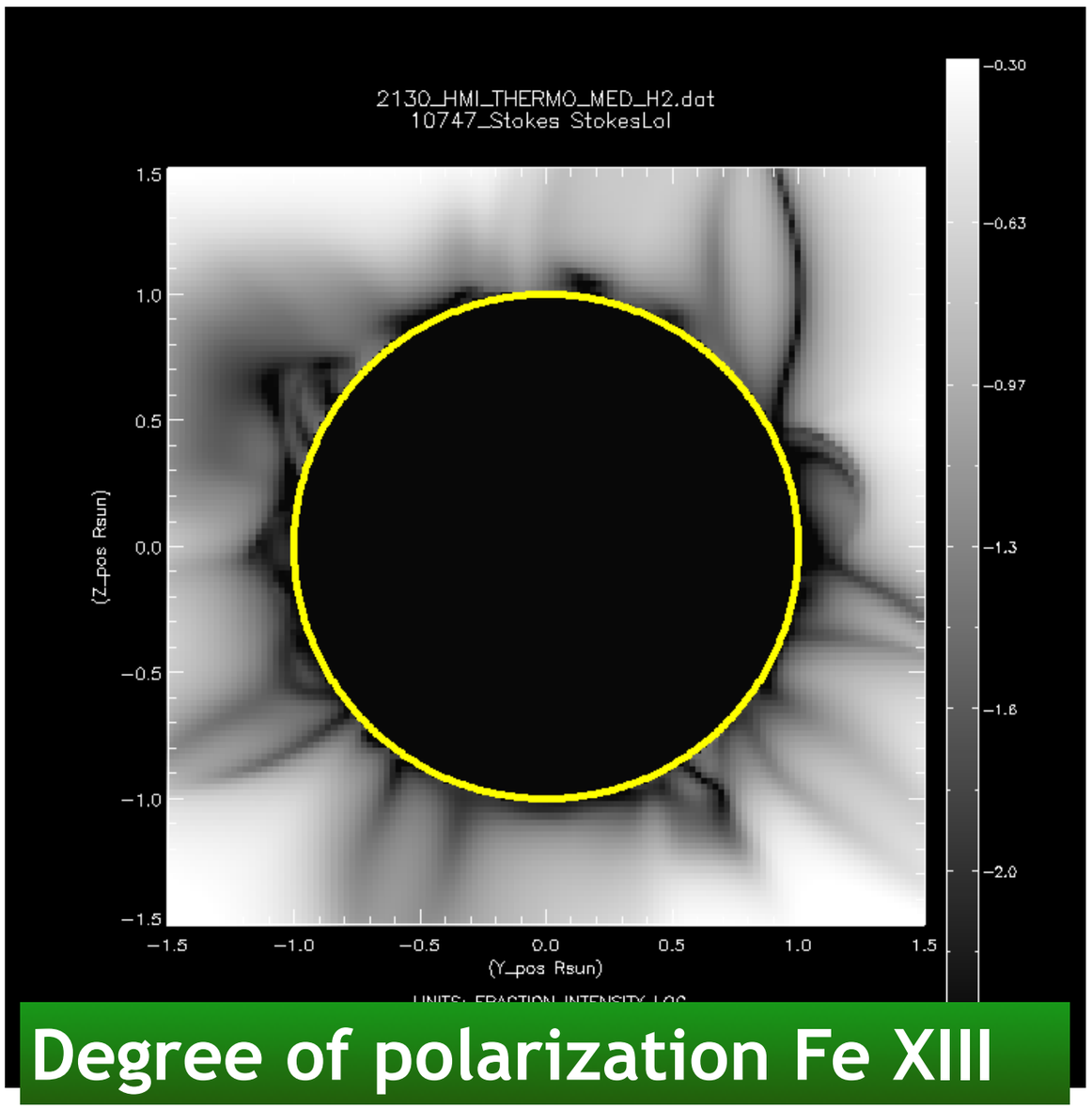
Fe XIII Intensity

FORWARD SolarSoft IDL package

- Given plasma/magnetic fields synthesizes multi-λ observables
- Works with any analytic or numerical model
- Applies CLE code of Judge & Casini for visible/IR polarimetry



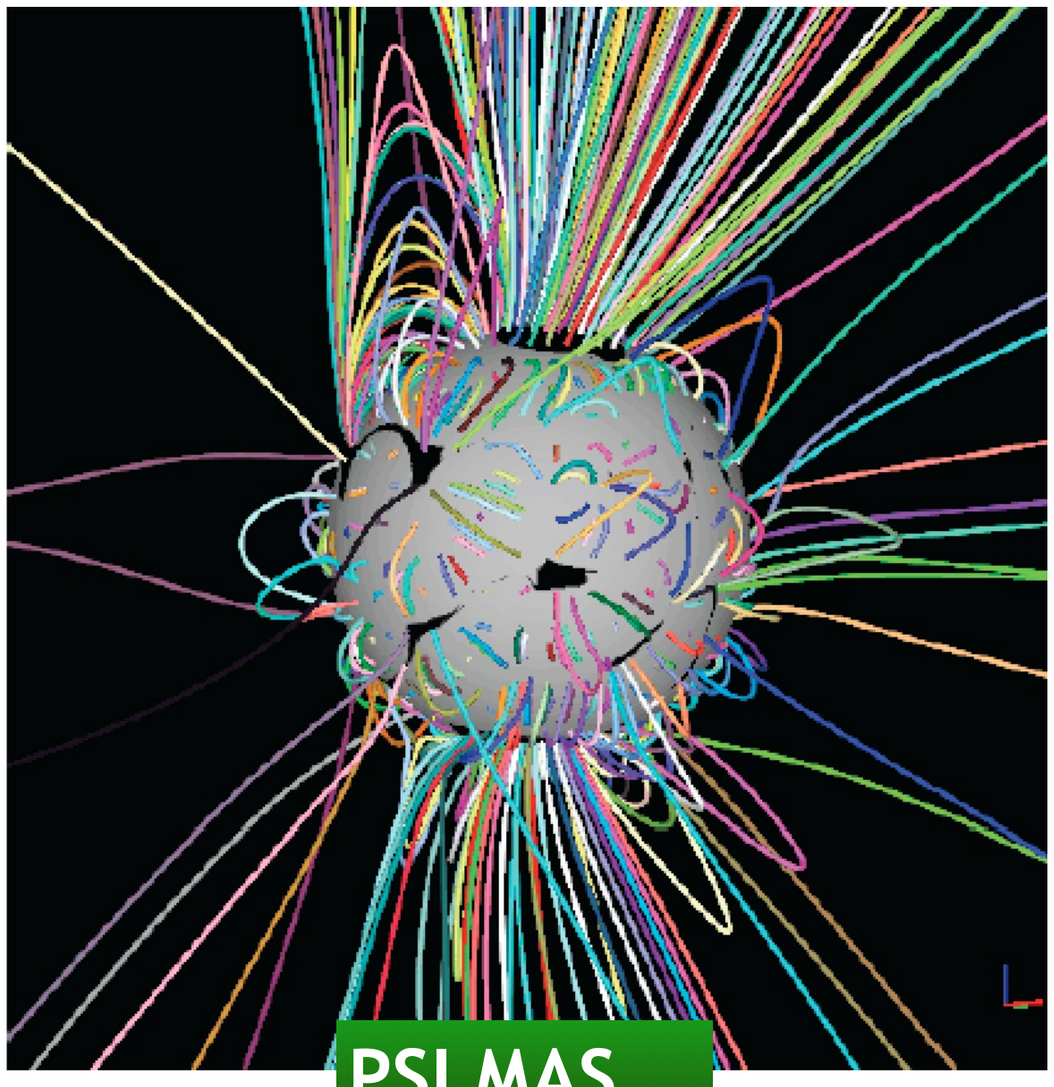
PSI MAS



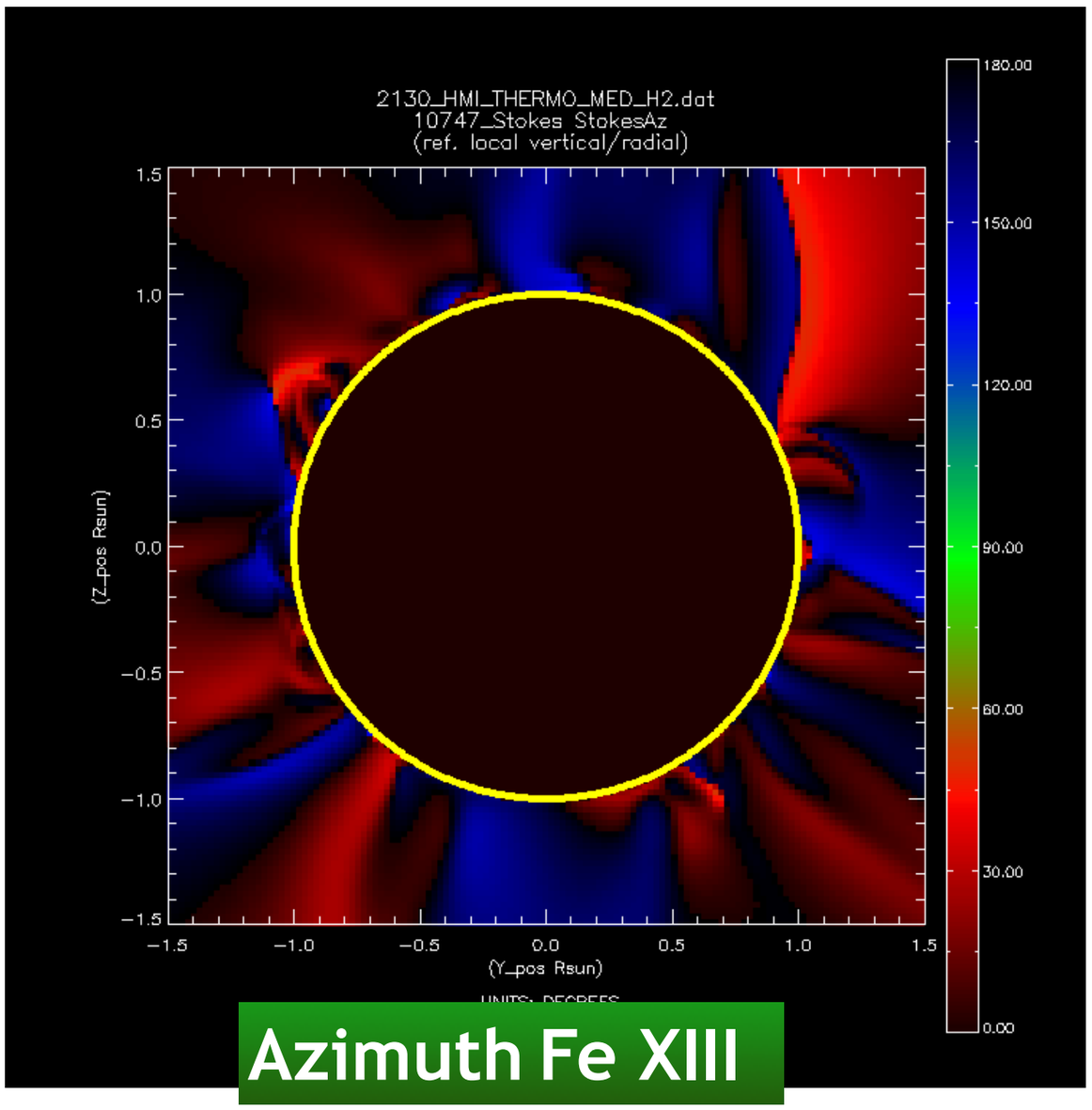
Degree of polarization Fe XIII

FORWARD SolarSoft IDL package

- Given plasma/magnetic fields synthesizes multi-λ observables
- Works with any analytic or numerical model
- Applies CLE code of Judge & Casini for visible/IR polarimetry



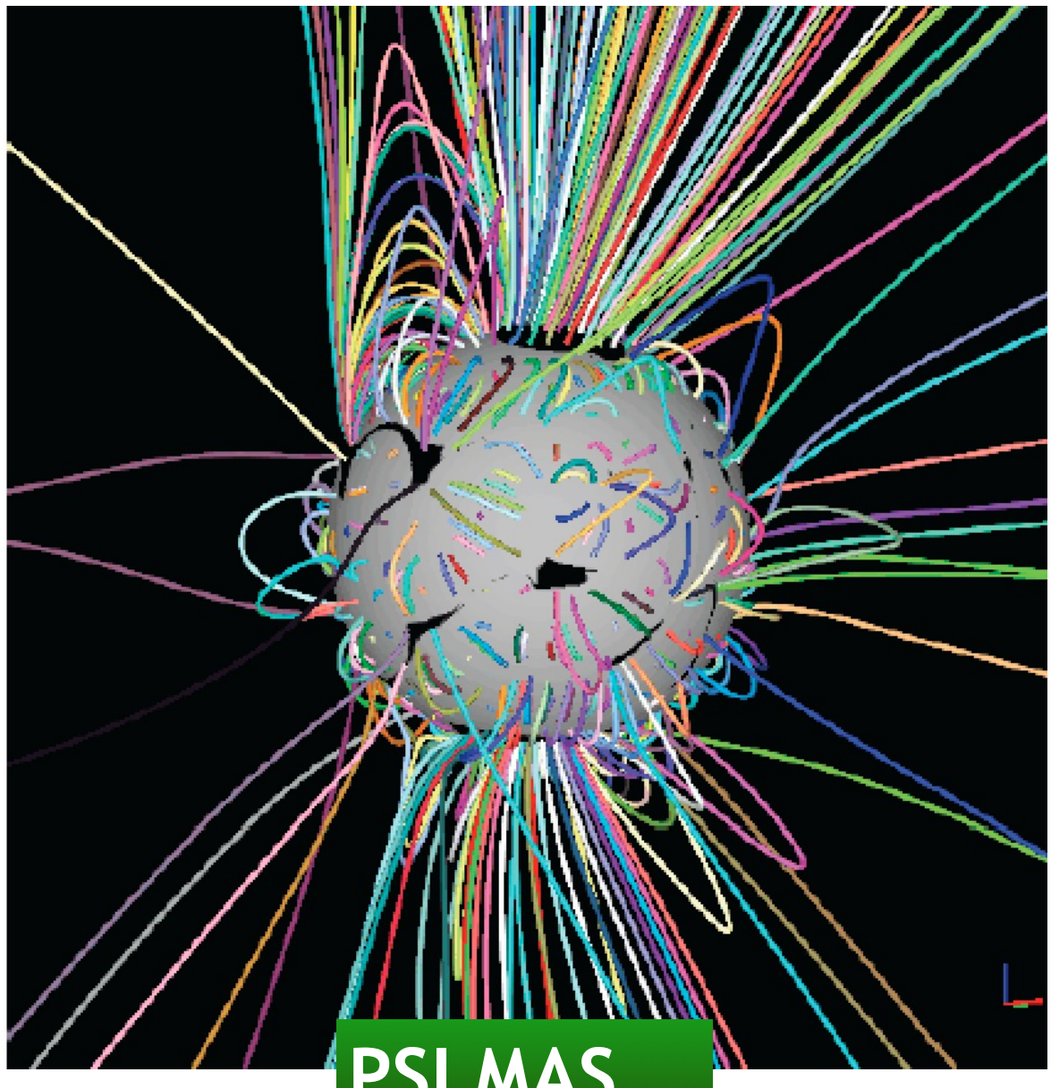
PSI MAS



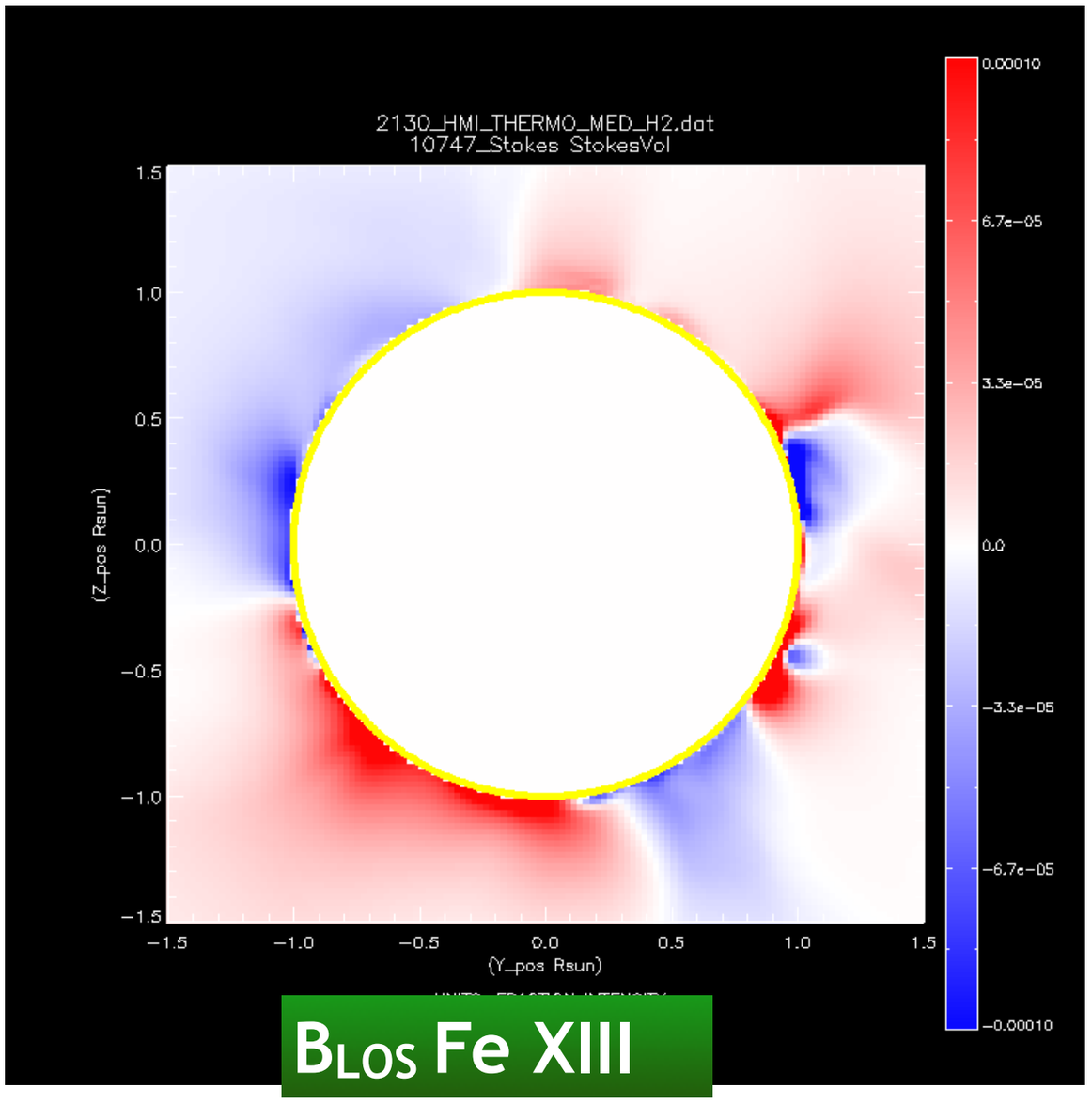
Azimuth Fe XIII

FORWARD SolarSoft IDL package

- Given plasma/magnetic fields synthesizes multi-λ observables
- Works with any analytic or numerical model
- Applies CLE code of Judge & Casini for visible/IR polarimetry



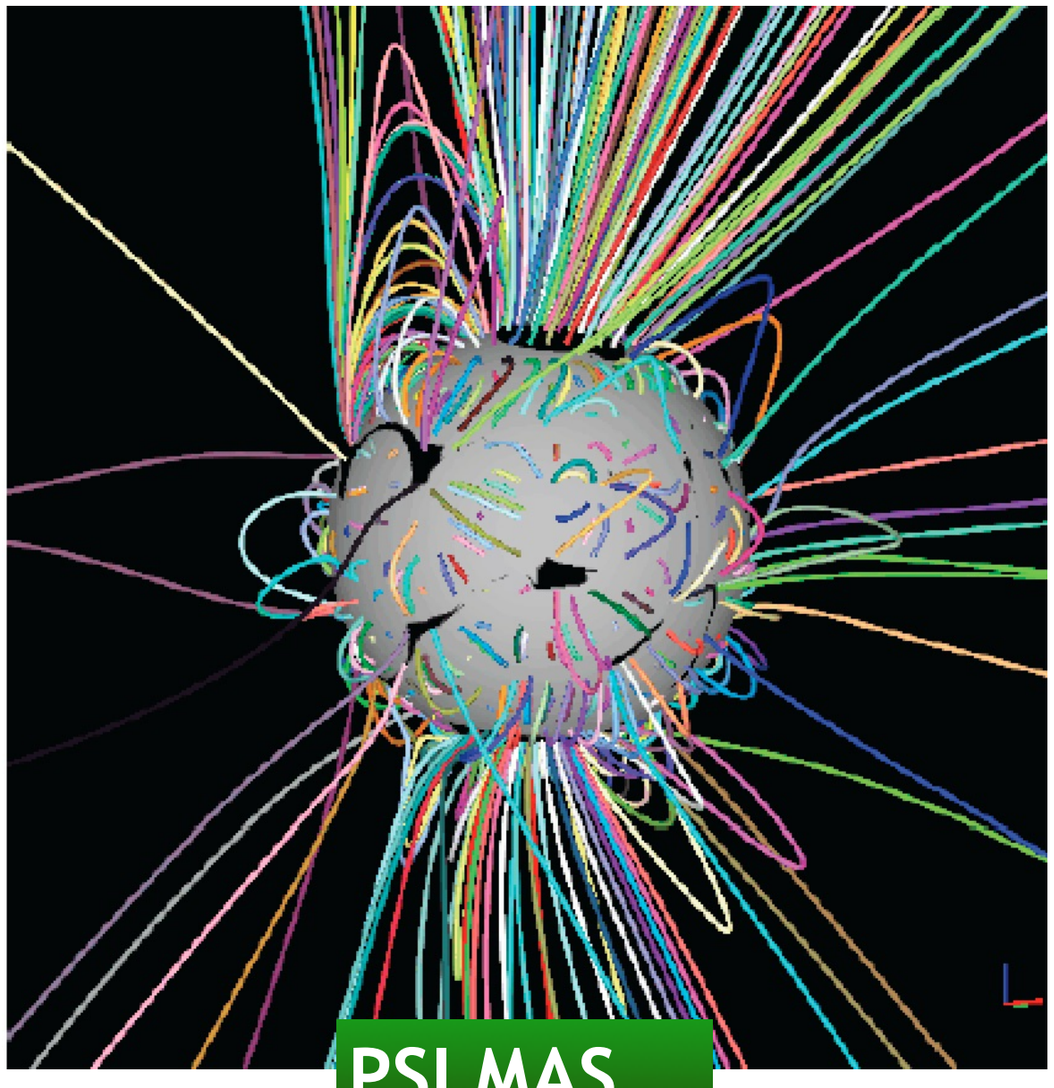
PSI MAS



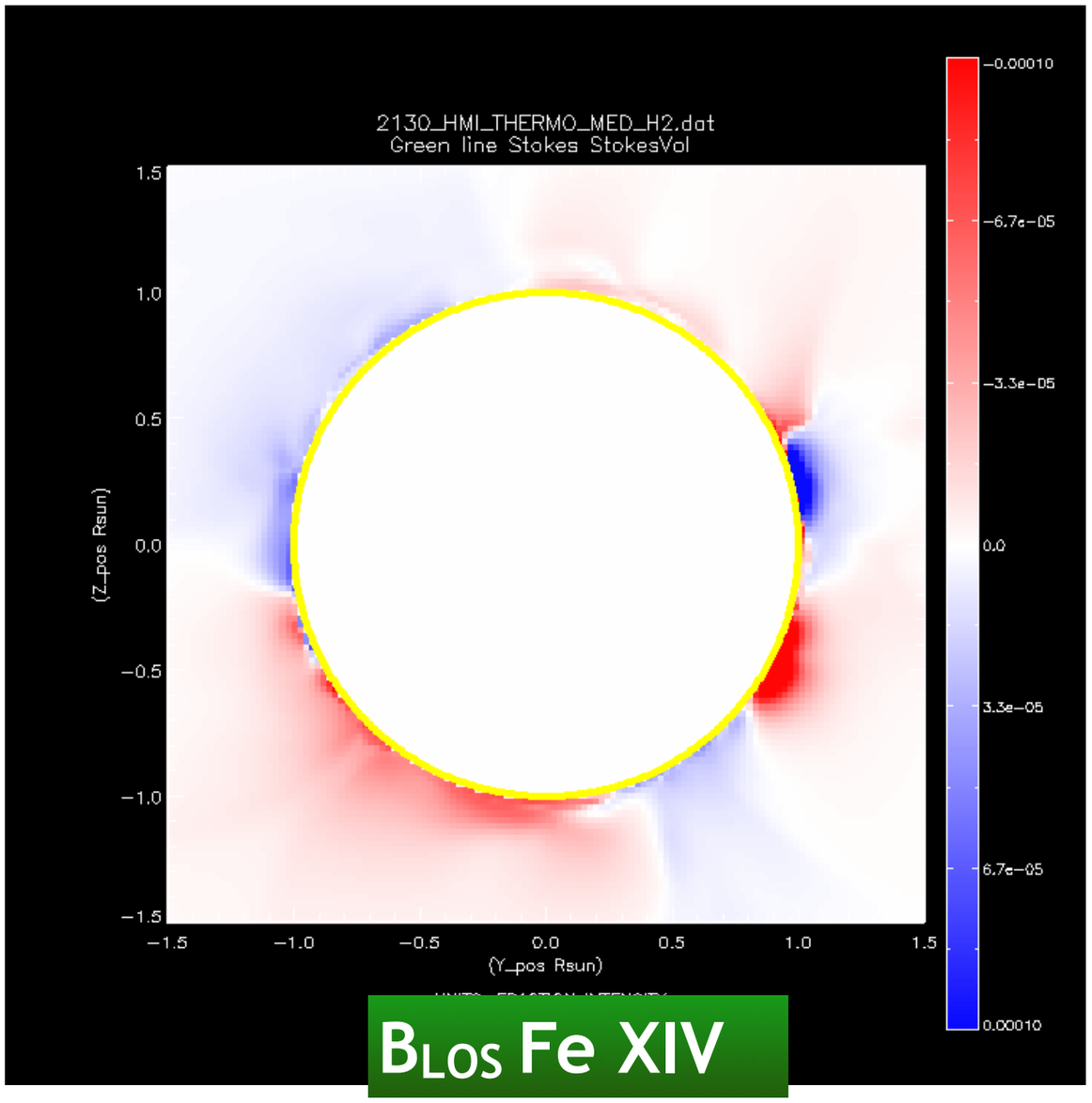
B_{LOS} Fe XIII

FORWARD SolarSoft IDL package

- Given plasma/magnetic fields synthesizes multi-λ observables
- Works with any analytic or numerical model
- Applies CLE code of Judge & Casini for visible/IR polarimetry



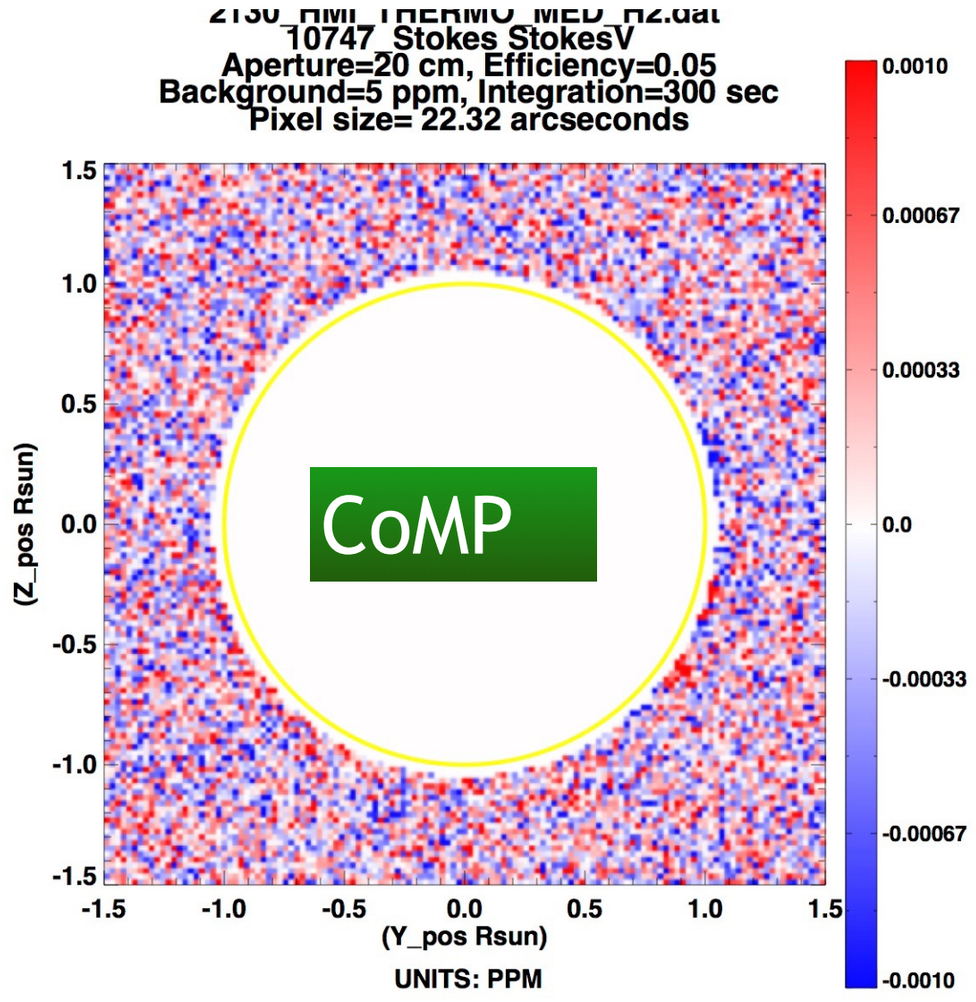
PSI MAS

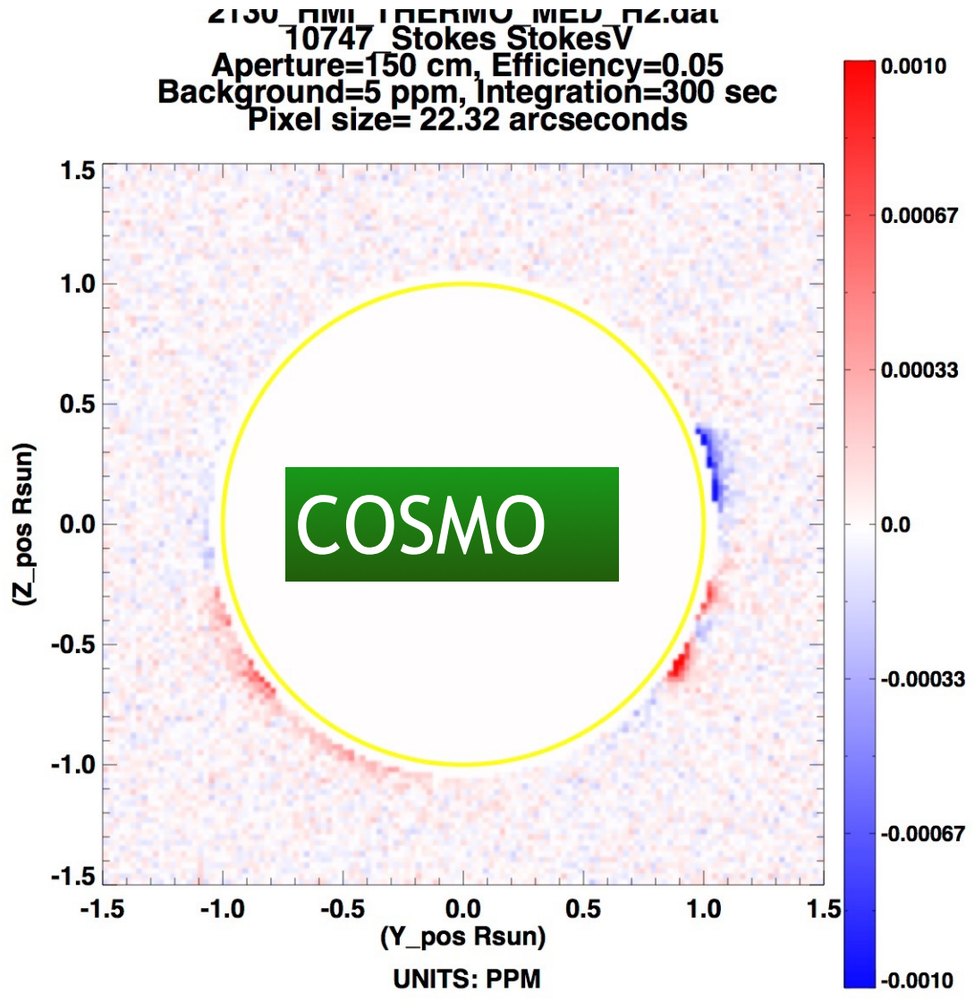


B_{LOS} Fe XIV

FORWARD SolarSoft IDL package

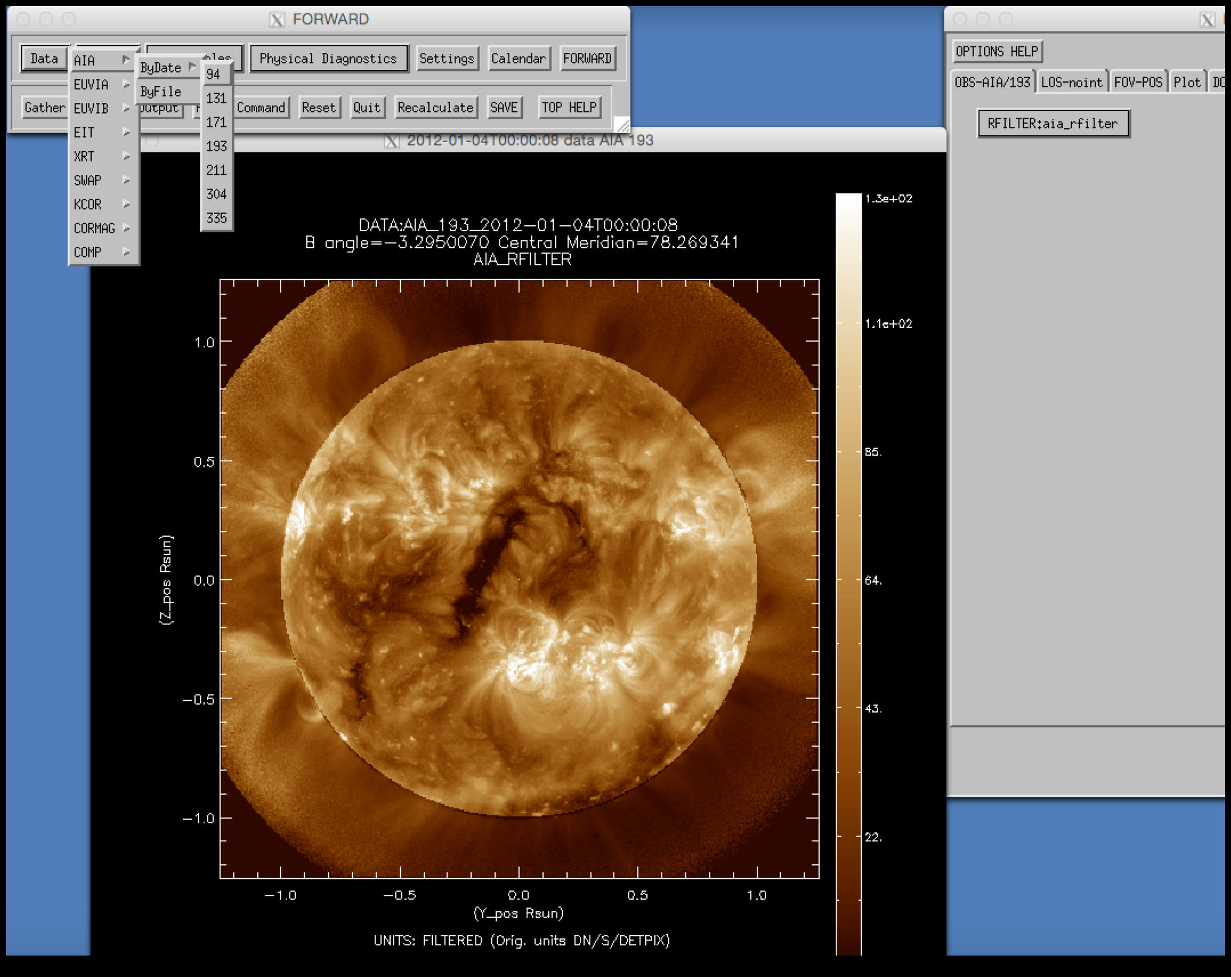
- Can add photon noise to telescope specifications



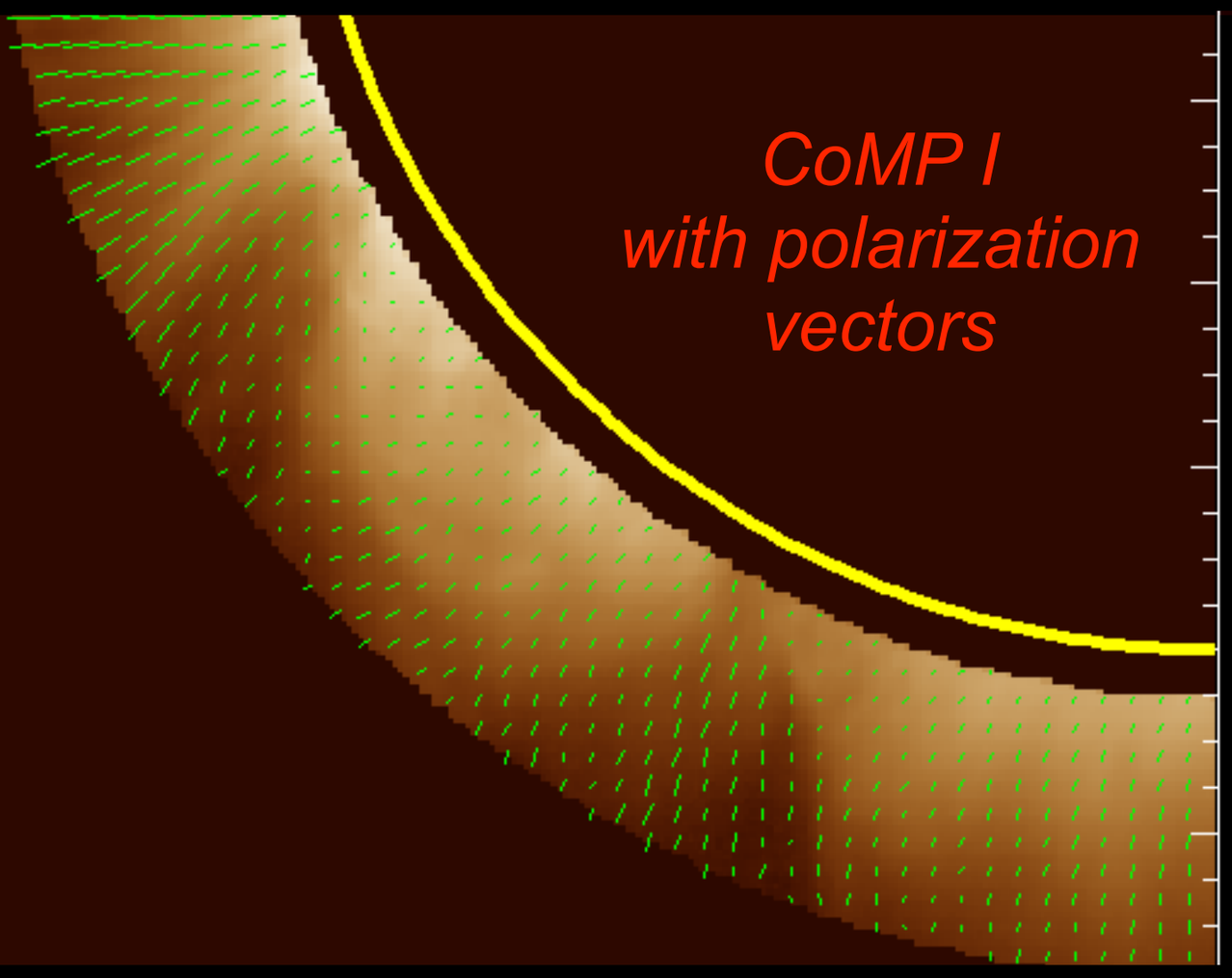


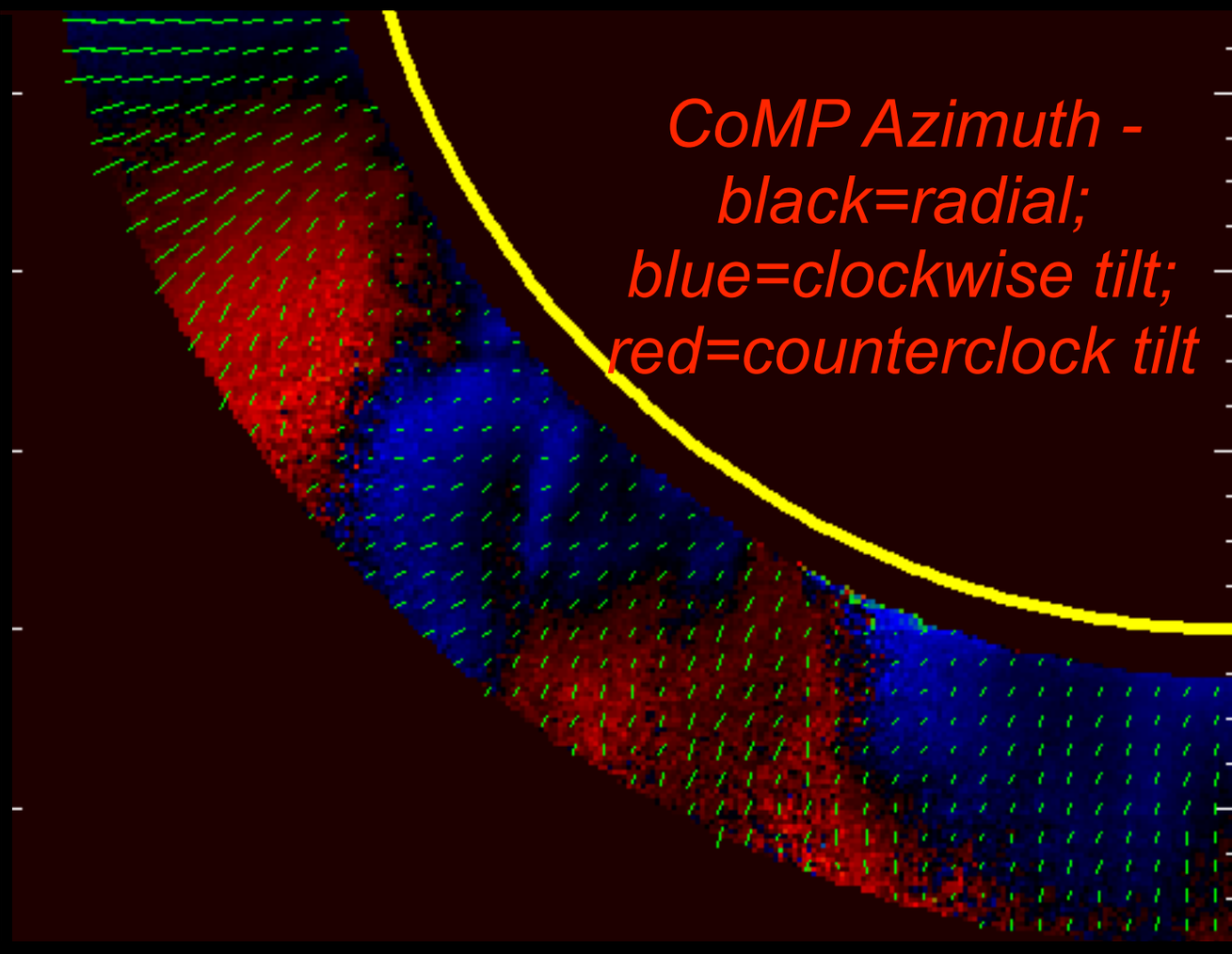
5 minute integration of circular polarization for Fe XIII

Observations



Observations

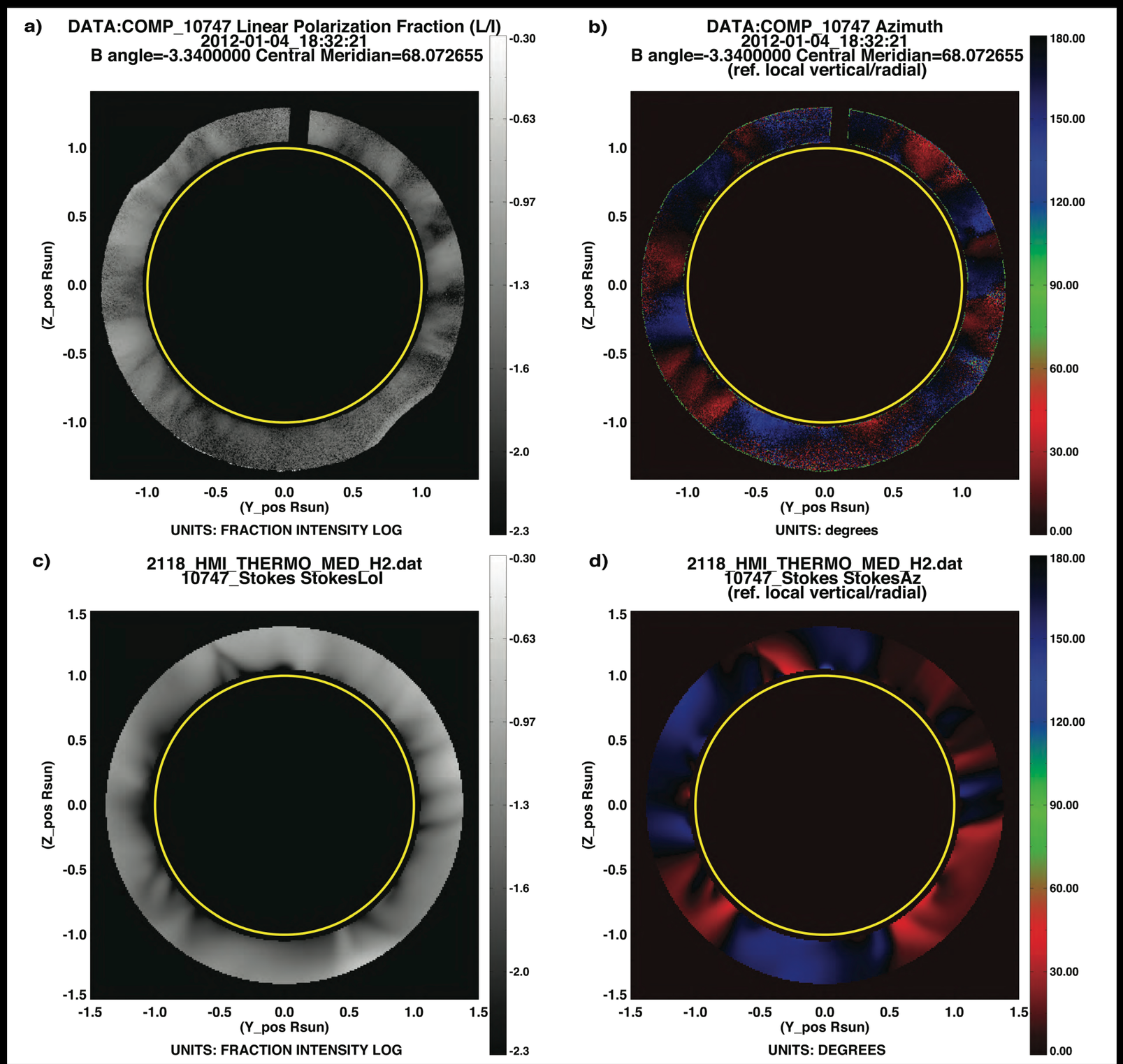




- Measures POS magnetic direction (with 90 degree flip when crosses V. Vleck angle)
- Quantifies expansion of flux tubes (significant to solar wind acceleration)

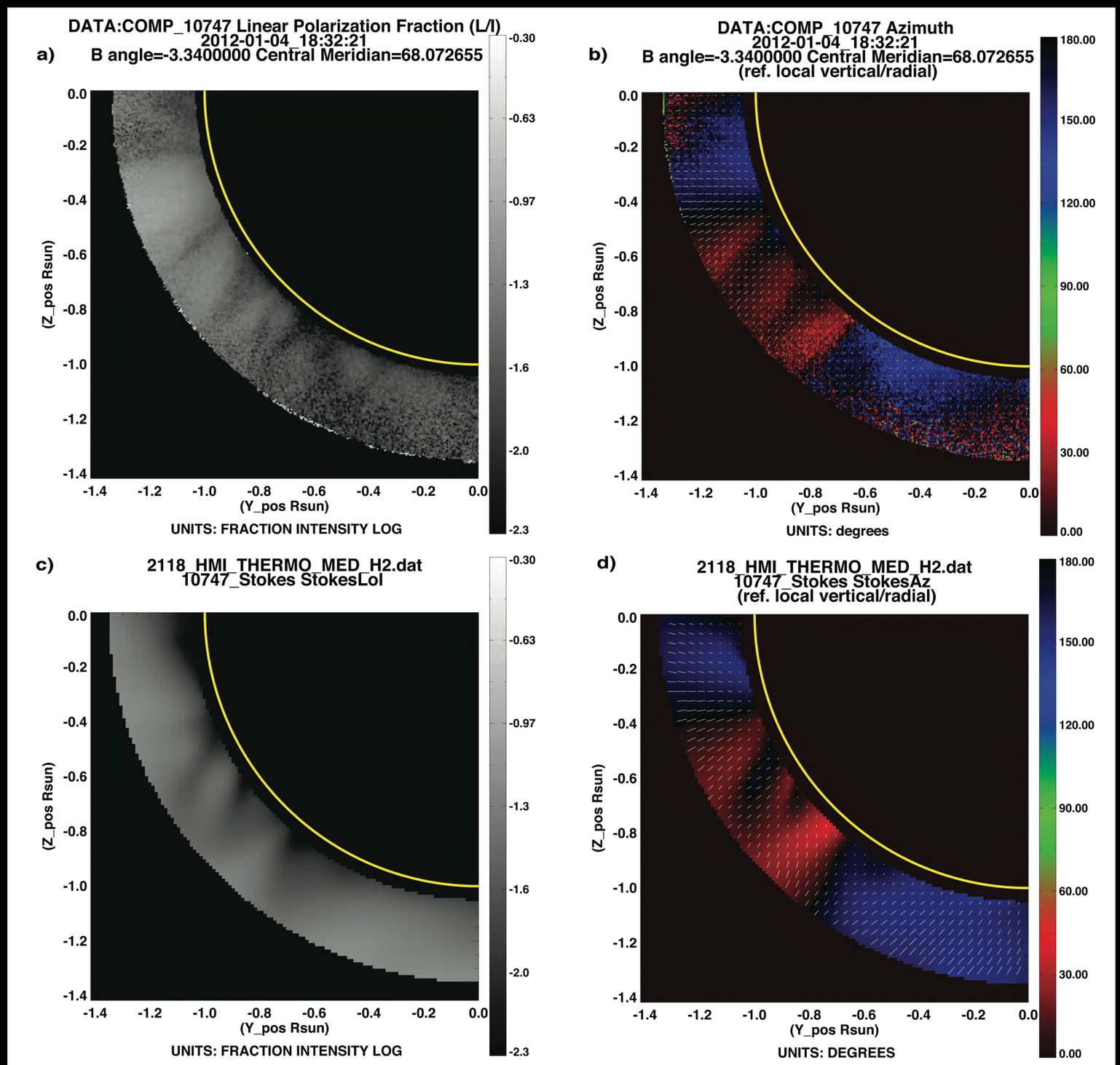
Model-data comparison

Model validation



Model-data comparison

Model validation

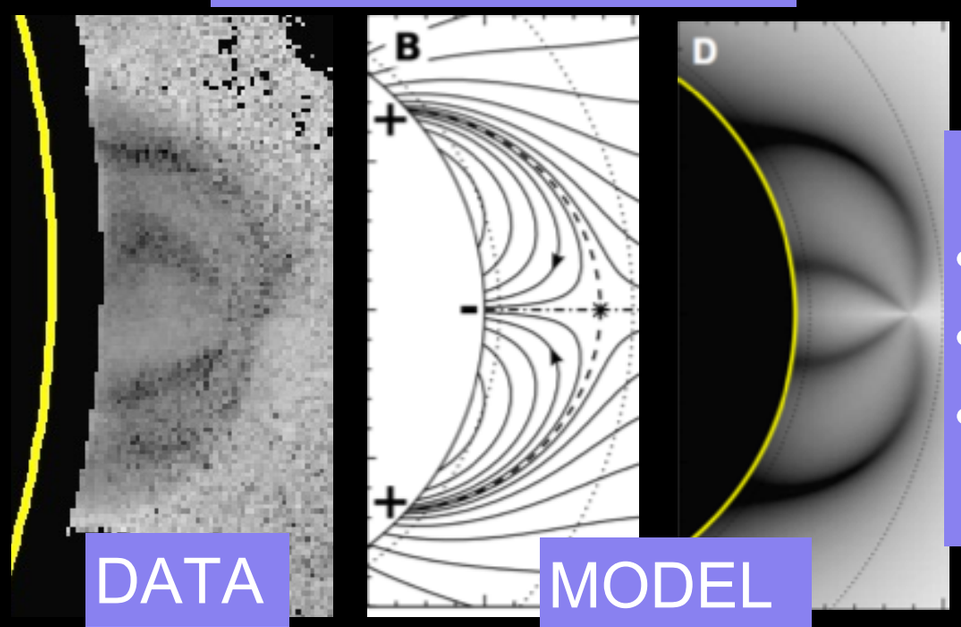


Model-data comparison

Building intuition

Magnetic nulls

$$L / I = \frac{(Stokes\ Q^2 + Stokes\ U^2)^{1/2}}{Stokes\ I}$$



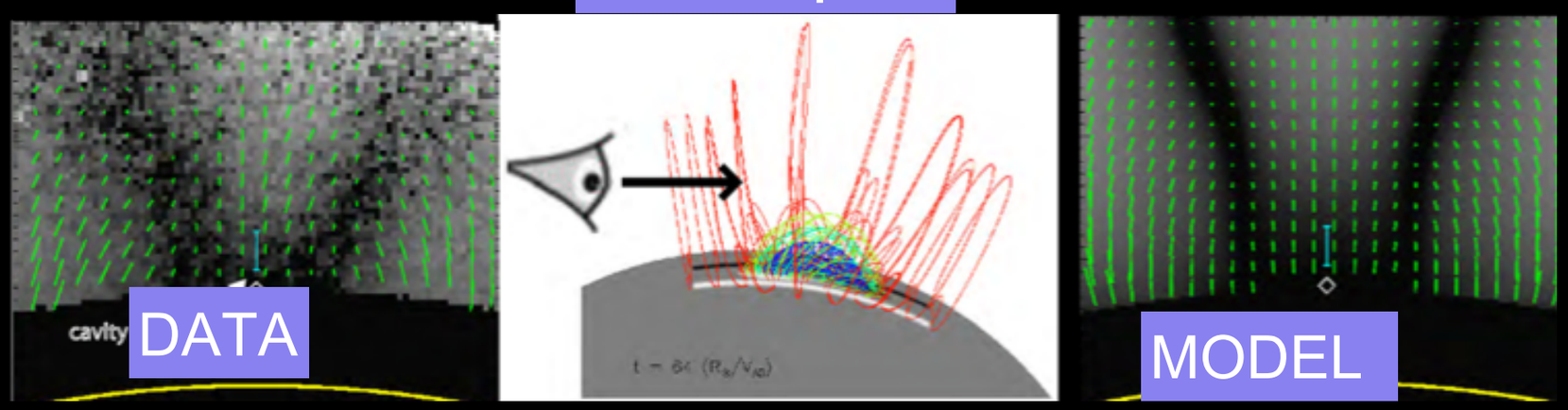
Gibson et al., 2017

(Saturated) Hanle effect: depolarization

- Strong **L/I** signal: **B** in plane of sky
- zero: **B** along line of sight
- zero: Van Vleck angle (between **B** and radial) = 54.74

Diagnostic of magnetic topology (significant for predicting eruptions)

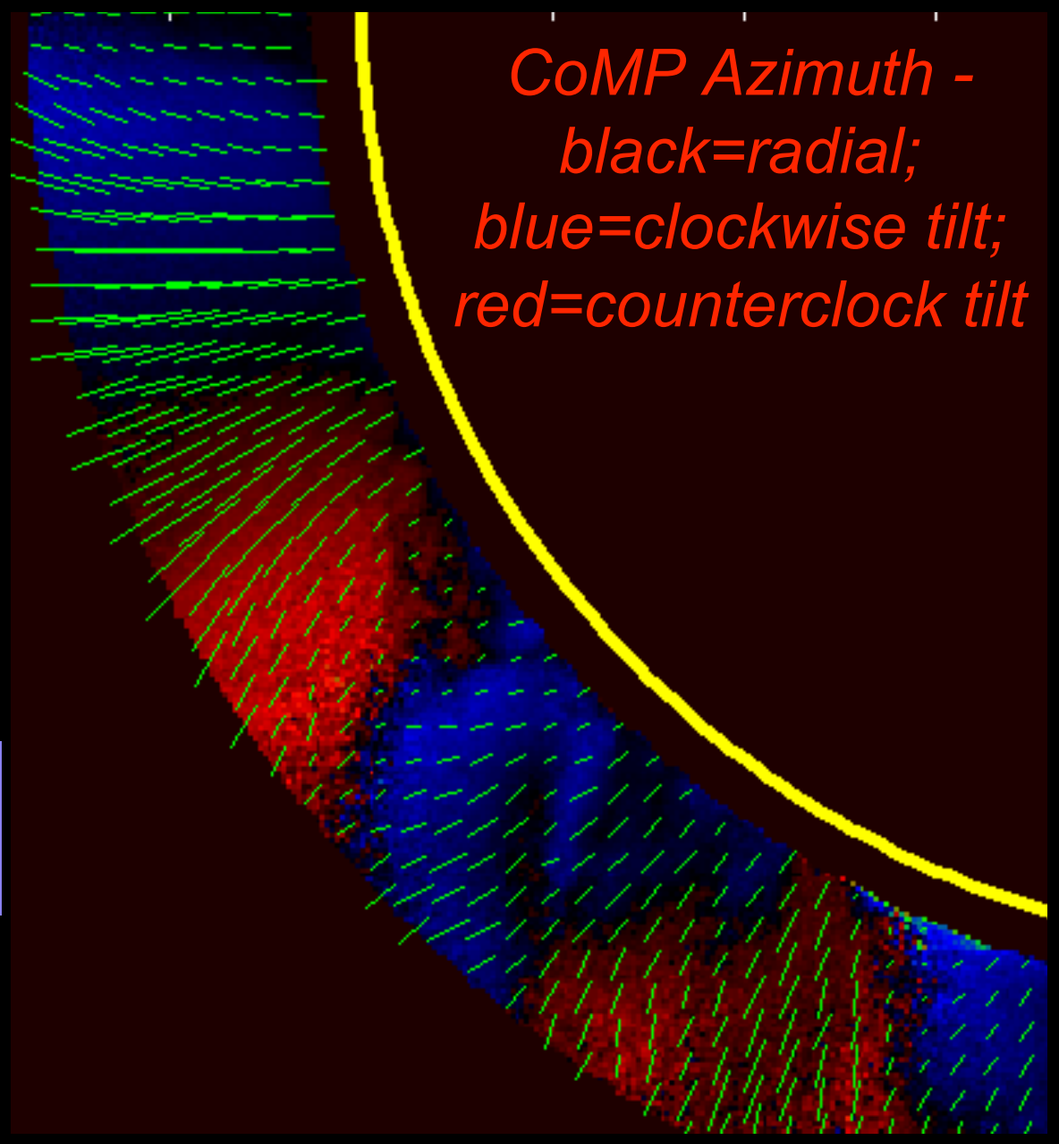
Flux ropes



Model-data comparison

Building intuition

$$Az = 0.5 \tan^{-1}\left(\frac{Stokes\ U}{Stokes\ Q}\right)$$



diverging fields

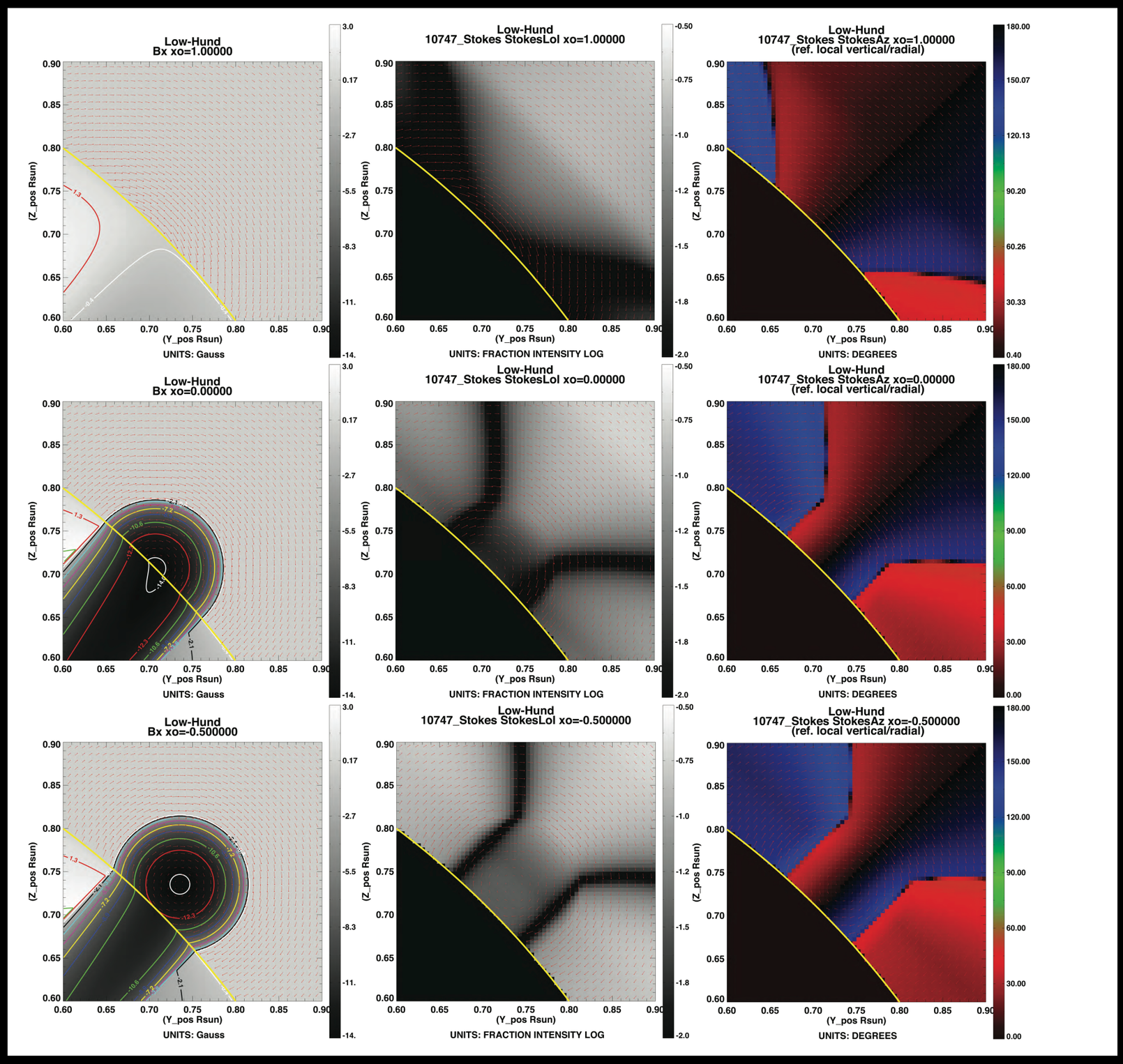
converging fields

Linear polarization azimuth = direction of POS vector (but rotates 90 degrees at V. Vleck angle!)

Diagnostic of non-radial expansion

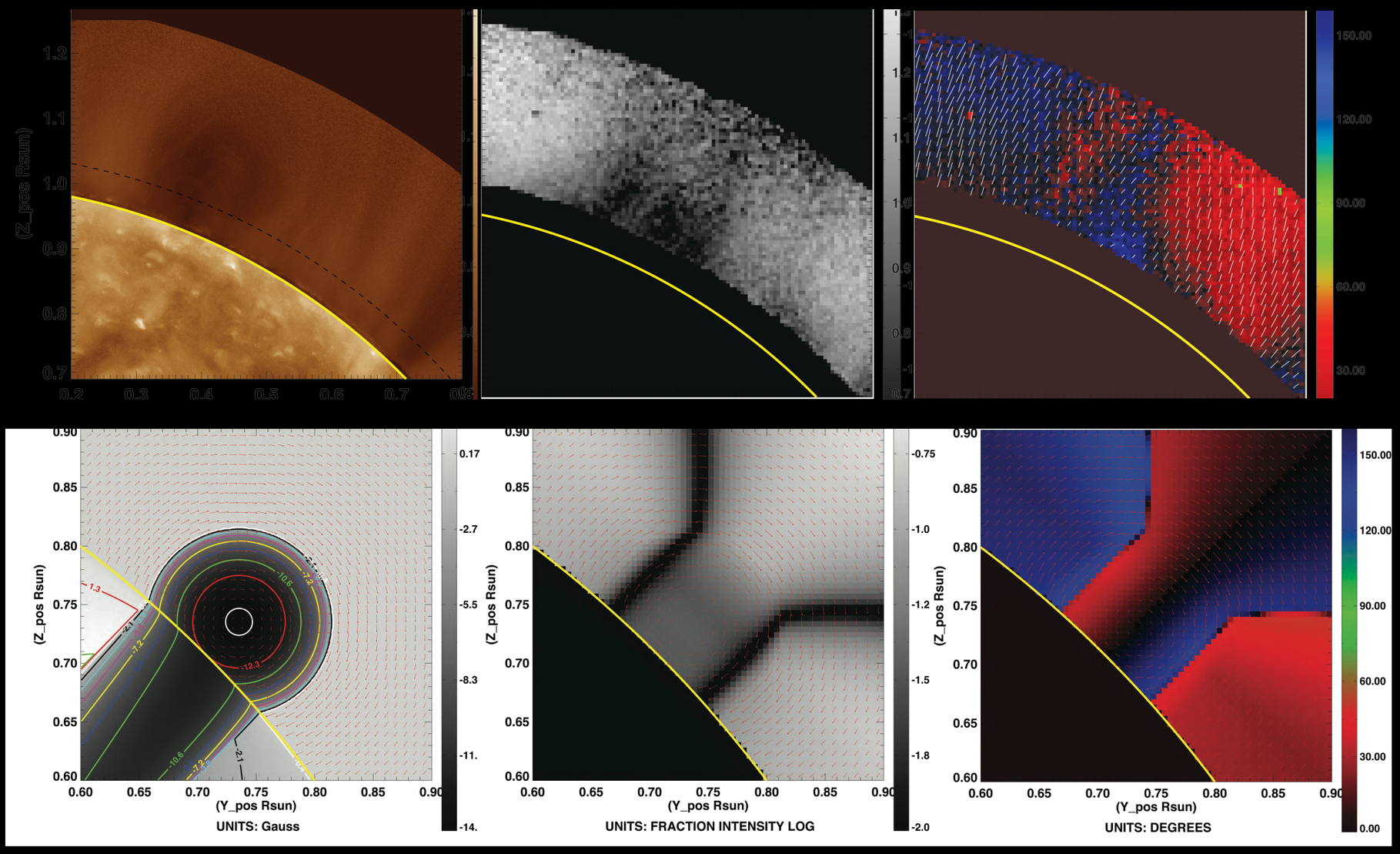
Model-data comparison

Forward fitting

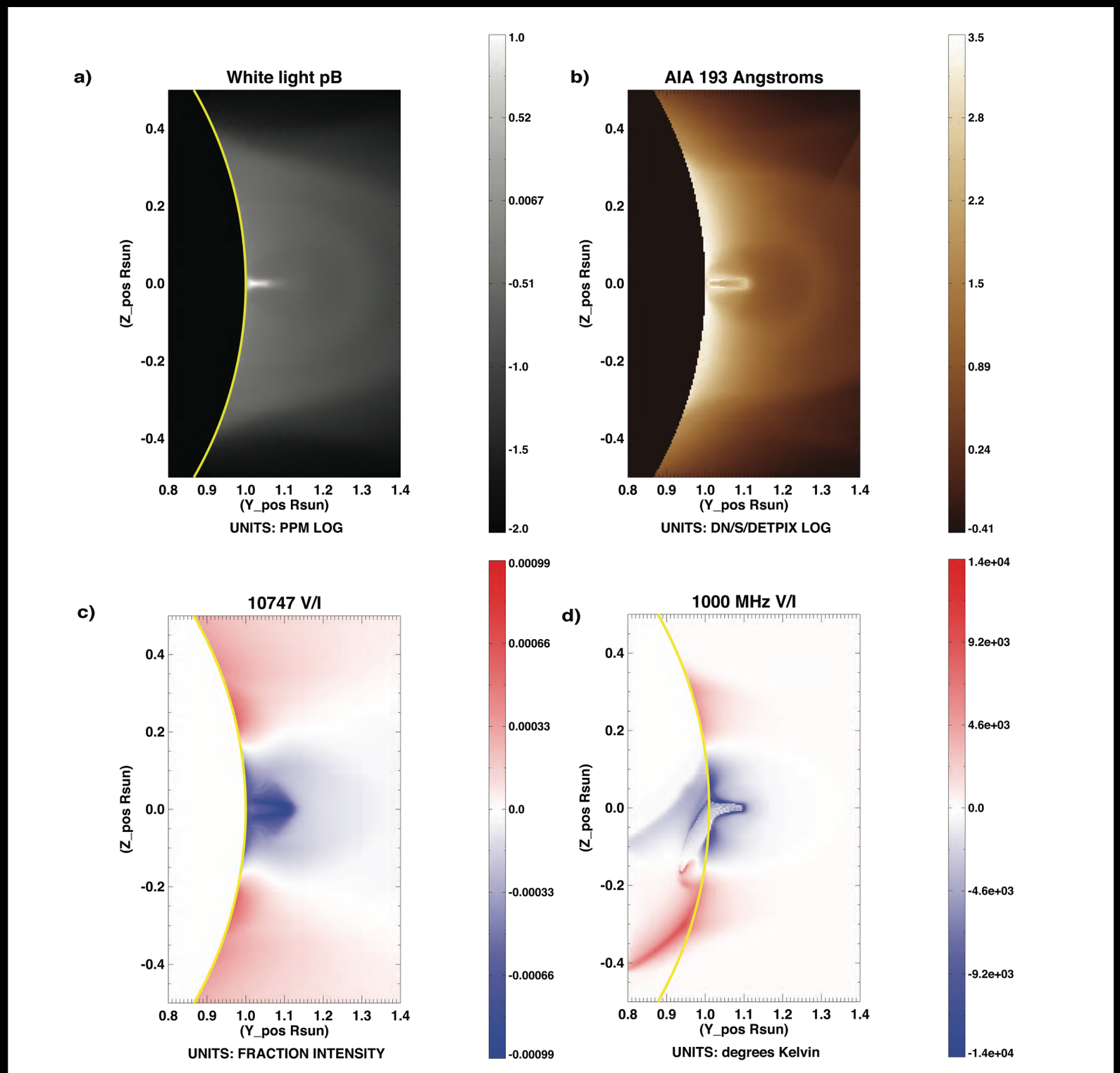


Model-data comparison

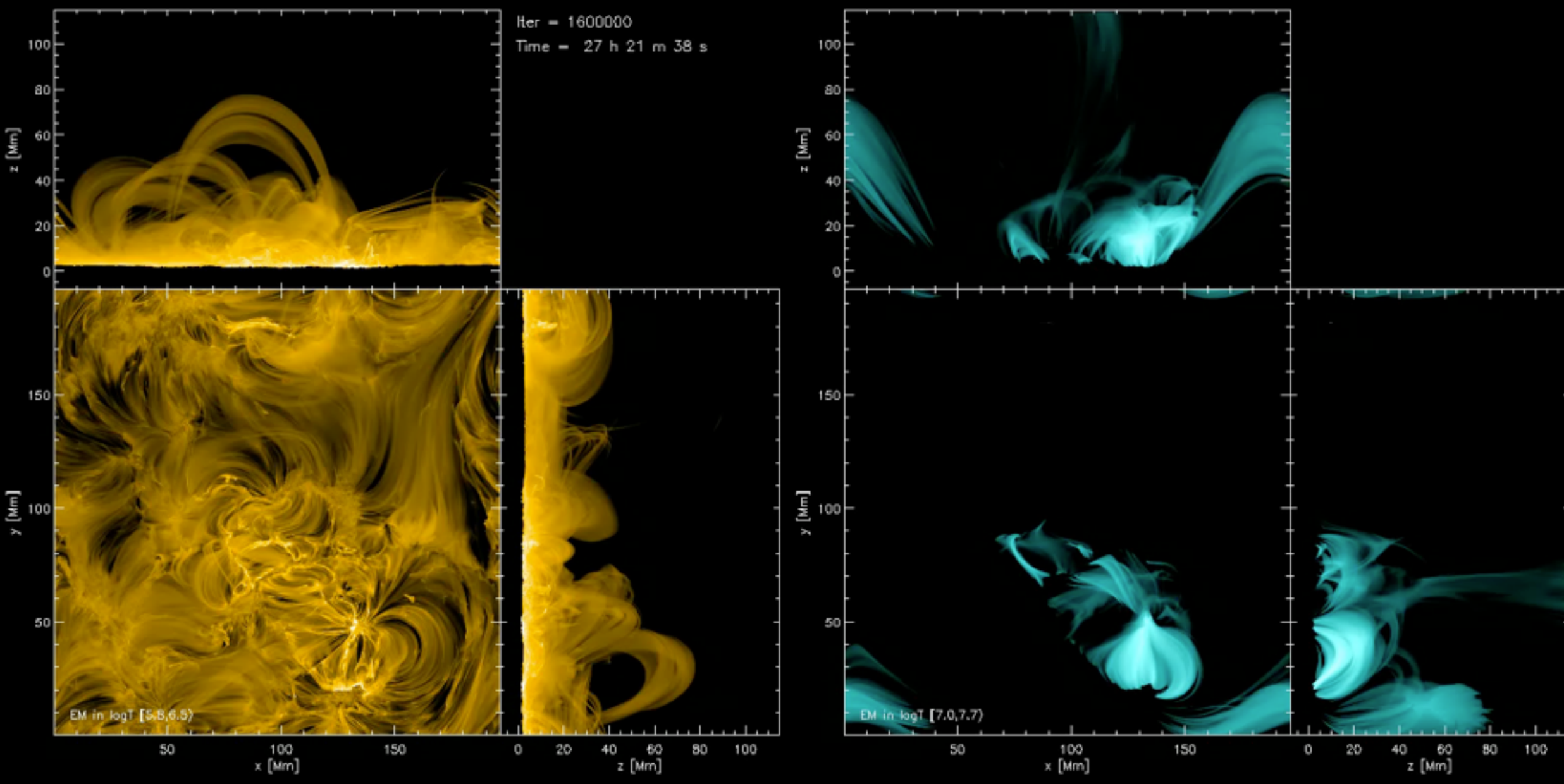
Forward fitting



Synthetic test beds

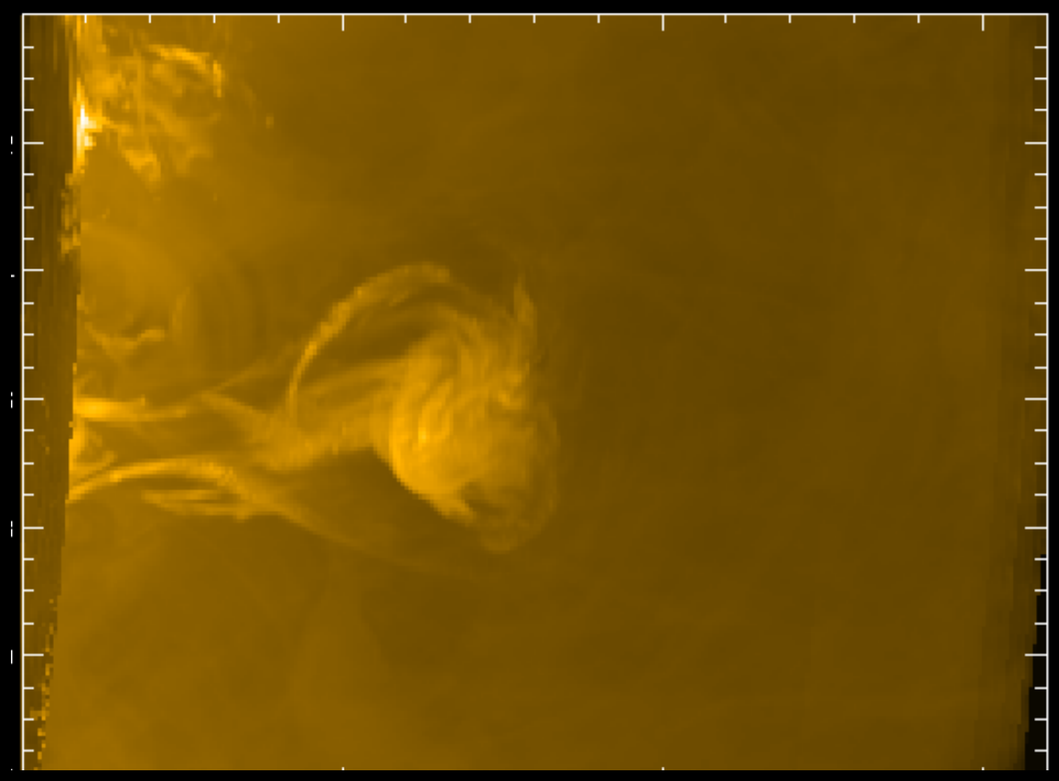


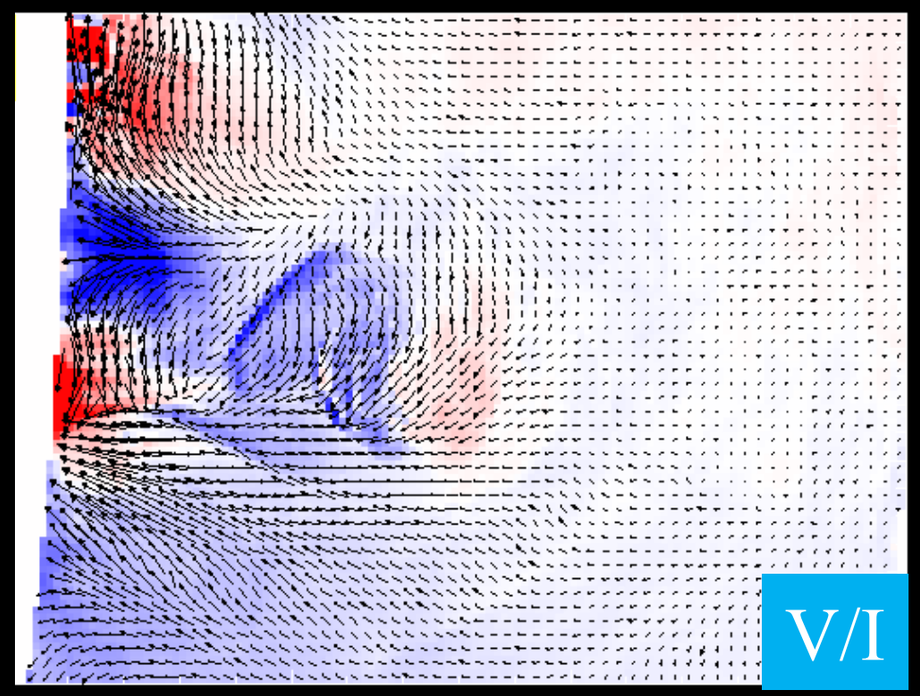
Fan, 2015 flux rope simulation - included with FORWARD distribution

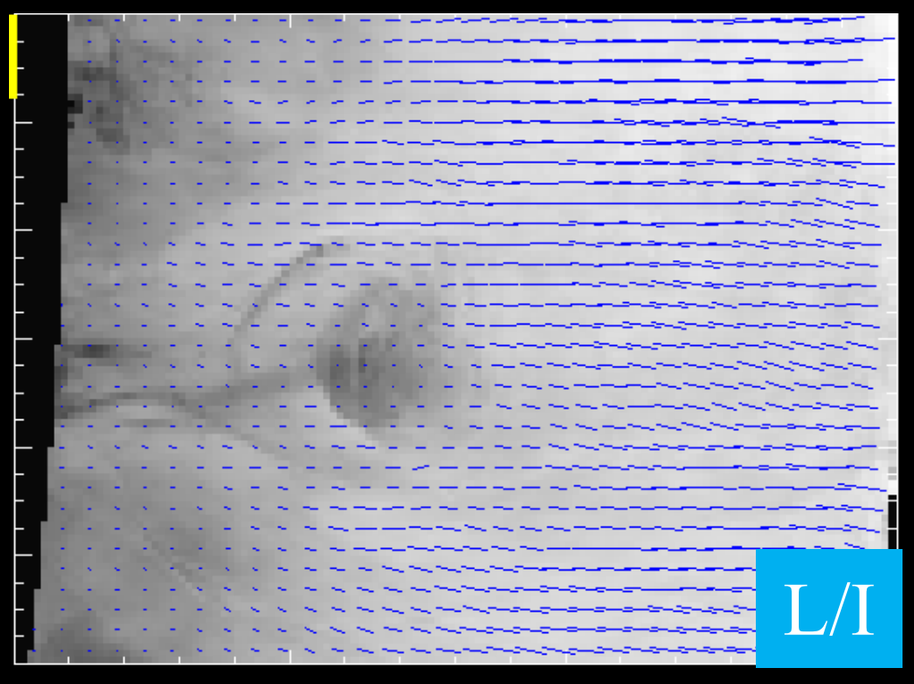


Emerging active region: Rempel, 2017

Synthetic test beds







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

Conclusions

- A range of magnetically sensitive physical processes have observational signatures **in the corona** at wavelengths from radio to soft Xray

- FORWARD is a community toolset for model-data comparison, enabling model validation, building intuition for coronal magnetic signatures, and forward fitting/inversion applications

- Synthetic testbeds provide a “ground truth” against which to test new methodologies for multi wavelength coronal magnetometry