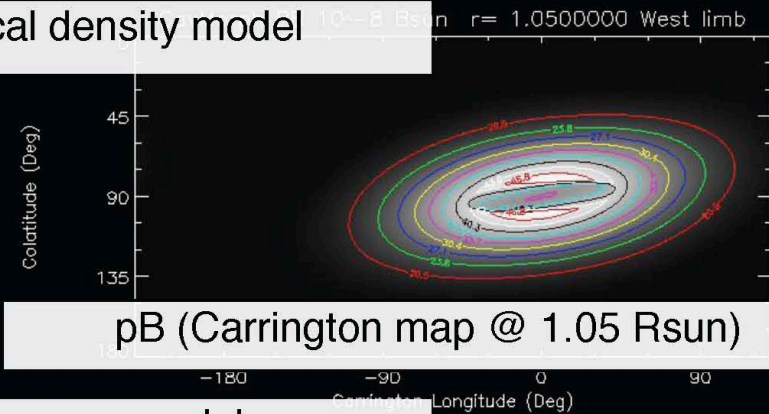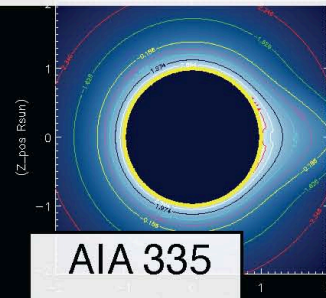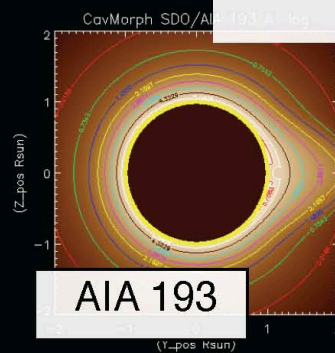# Sarah Gibson   NCAR/HAO

- community resource for model-data comparison; emphasis on coronal magnetometry
- synthesizes a range of coronal observables and accesses and compares to existing data
- enables "forward-fitting" of specific observations
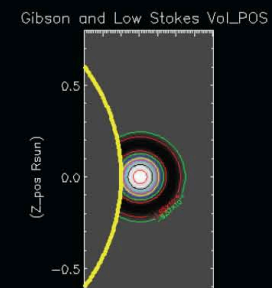- helps to build intuition into how physical properties translate to observable properties.

http://people.hao.ucar.edu/sgibson/FORWARD/

Sarah Gibson

http://people.hao.ucar.edu/sgibson/FORWARD/
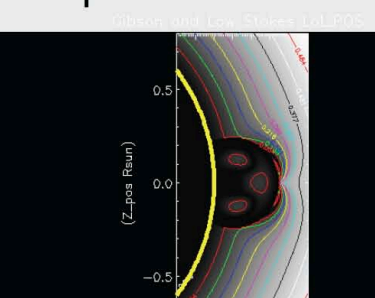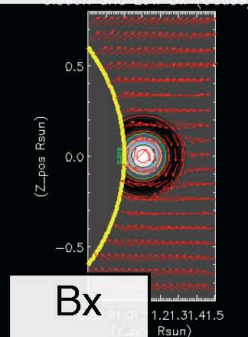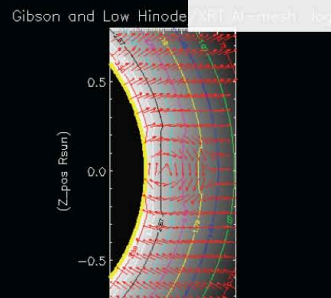
The **FORWARD** suite of **SolarSoft IDL** codes is a community resource for model-data comparison, with a particular emphasis on analyzing coronal magnetic fields. **FORWARD** may be used both to synthesize a broad range of coronal observables, and to access and compare to existing data. **FORWARD** enables "forward-fitting" of specific observations, and helps to build intuition into how the physical properties of coronal magnetic structures translate to observable properties.

FORWARD code contributors

Authors of SolarSoft IDL routines currently in FORWARD:

- **Sarah Gibson**
- **Terry Kucera**
- **James Dove**
- **Laurel Rachmeler**
- **Blake Forland**

- **Tim Bastian**
- **Stephen White**
- **Silvano Fineschi**

- **Cooper Downs**
- **Haosheng Lin**
- **Don Schmit**
- **Kathy Reeves**
- **Chris Bethge**
- **Yuhong Fan**

FORWARD code interfaces

Authors/liasons to codes and datacubes linked to FORWARD:

- **Phil Judge**, **Roberto Casini**: CLE Fortran polarimetry code
  http://people.hao.ucar.edu/judge/homepage/
  (modified CLE version included in FORWARD distribution)

- **Jon Linker**, **Cooper Downs**: PSI MAS coronal MHD model
  http://www.predsci.com/hmi/dataAccess.php
  (MAS Carrington rotation datacubes accessed via FORWARD
  calendar interface)

- **Marc de Rosa**: Potential Field Source Surface model
  http://www.lmsal.com/~derosa/pfsspack/
  (PFSS Carrington rotation datacubes accessed via FORWARD
  calendar interface; add'l calls to PFSS package routines)

FORWARD code interfaces

Authors/liasons to codes and datacubes linked to FORWARD:

- **Enrico Landi**: CHIANTI atomic database for spectroscopy
  http://www.chiantidatabase.org/instructions.html
  (Chianti spectral line calculations used to build databases)

- **Joe Hourcle, Dominic Zarro**: VSO SolarSoft access
  http://docs.virtualsolar.org/wiki/VsoIDL
  (AIA/EUVI/EIT data accessed via FORWARD calendar interface –
  SWAP and CoMP data through instrument web sites)

FORWARD model/data inputs

FORWARD includes several analytic models (*Low & Hundhausen, ApJ, 443, 818, 1995; Lites & Low, Sol. Phys., 91, 1997; Gibson & Low, ApJ, 493, 1998; Gibson et al., ApJ, 724, 2010*) in its distribution, and it is straightforward to expand it to incorporate other analytic models. It works with user-inputted datacubes from numerical simulations, and automatically interfaces with the **Solar Soft** IDL ***Potential Field Source Surface (PFSS)*** package and *Magnetohydrodynamics on a Sphere (MAS)-corona* datacubes. In addition, it connects to the *Virtual Solar Observatory* and other web-served observations to download data in a format directly comparable to model predictions.

FORWARD calculations

Given a coronal model distribution of density, temperature, and (optional) vector magnetic field and velocity, many different synthetic observables may be produced through integration along a line of sight defined by the viewer's position in heliographic coordinates. **FORWARD** includes routines to reproduce data from **EUV/Xray imagers, UV/EUV spectrometers, white-light coronagraphs, and radio polarimeters.** It utilizes the *CHIANTI* database in modeling UV/EUV lines. In addition, **FORWARD** links to the *CLE* polarimetry synthesis code (Fortran77) for forbidden coronal lines, allowing synthesis of observatons from **visible to IR polarimeters**.

FORWARD outputs

FORWARD creates SolarSoft IDL maps of specified observable (**e.g. intensity, polarized Brightness, line width, Doppler velocity**). Maps of model plasma properties (**e.g. density, temperature, magnetic field, velocity**) may also be created.

Plane-of-sky and **Carrington plots** are both standard outputs, or the user may create **custom plots**. Either **command-line** or **widget** interfaces are available. **Image size, field-of-view**, and **resolution** can be adjusted. For the **CLE** output Stokes I,Q,U,V it is also possible to add **photon noise**, based on inputted telescope size, resolution, and time of integration.

Finally, information may be passed from one map to the next, enabling **model-model, data-data, model-data comparison**.

Data-data comparison
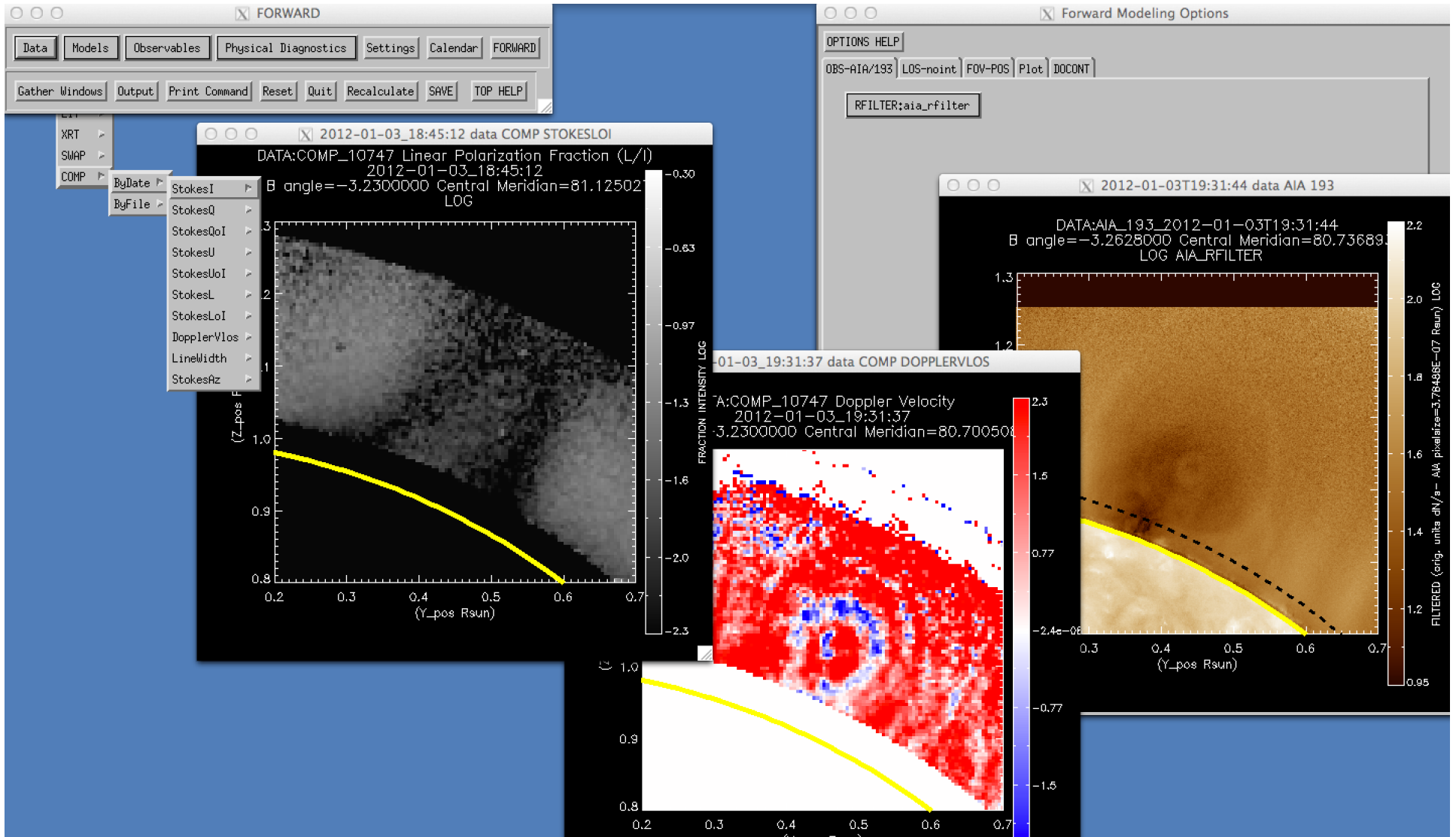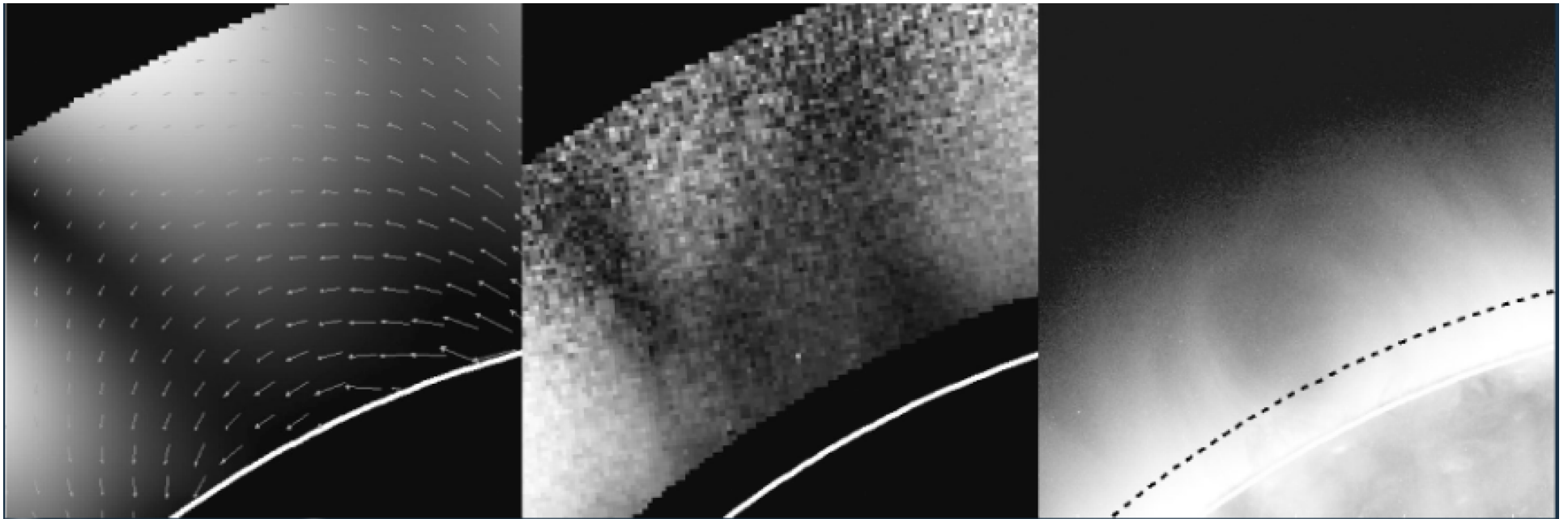
Intra/inter-model comparison
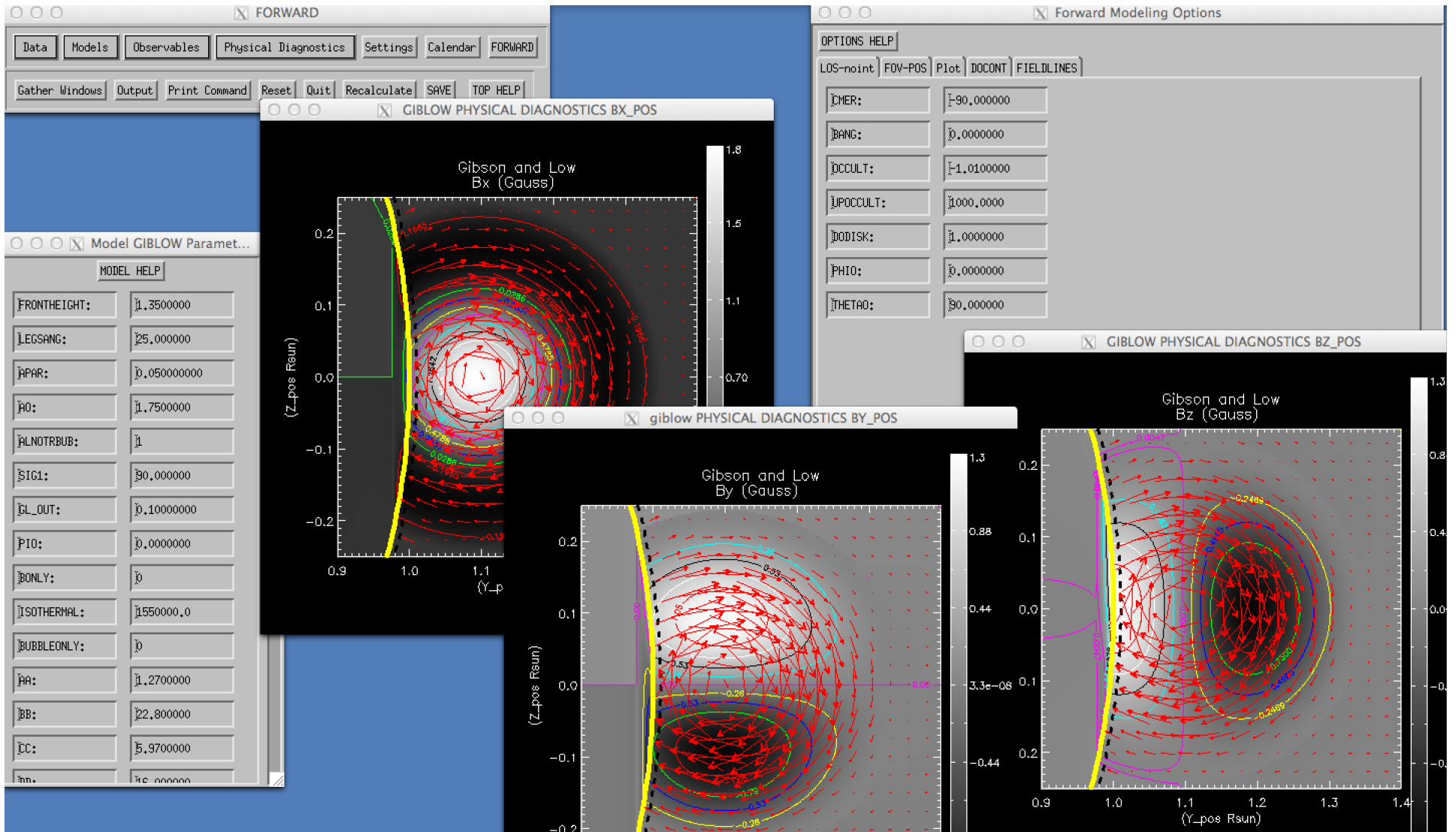
Model-data comparison

Stokes L=sqrt(Q^2+U^2) linear polarization

PFSS forward-modeled L/I   CoMP-measured L/I   AIA 193 Angstrom cavity

"Lagomorphs" are rabbit-head-shaped structures in linear polarization observed by the CoMP telescope to be associated to cavities observed in EUV emission (Bak-Steslicka et al, 2012). Forward modeling PFSS fields from the same day/viewpoint yields linear polarization structure with wider V-shaped ears and no clear dark central "head".

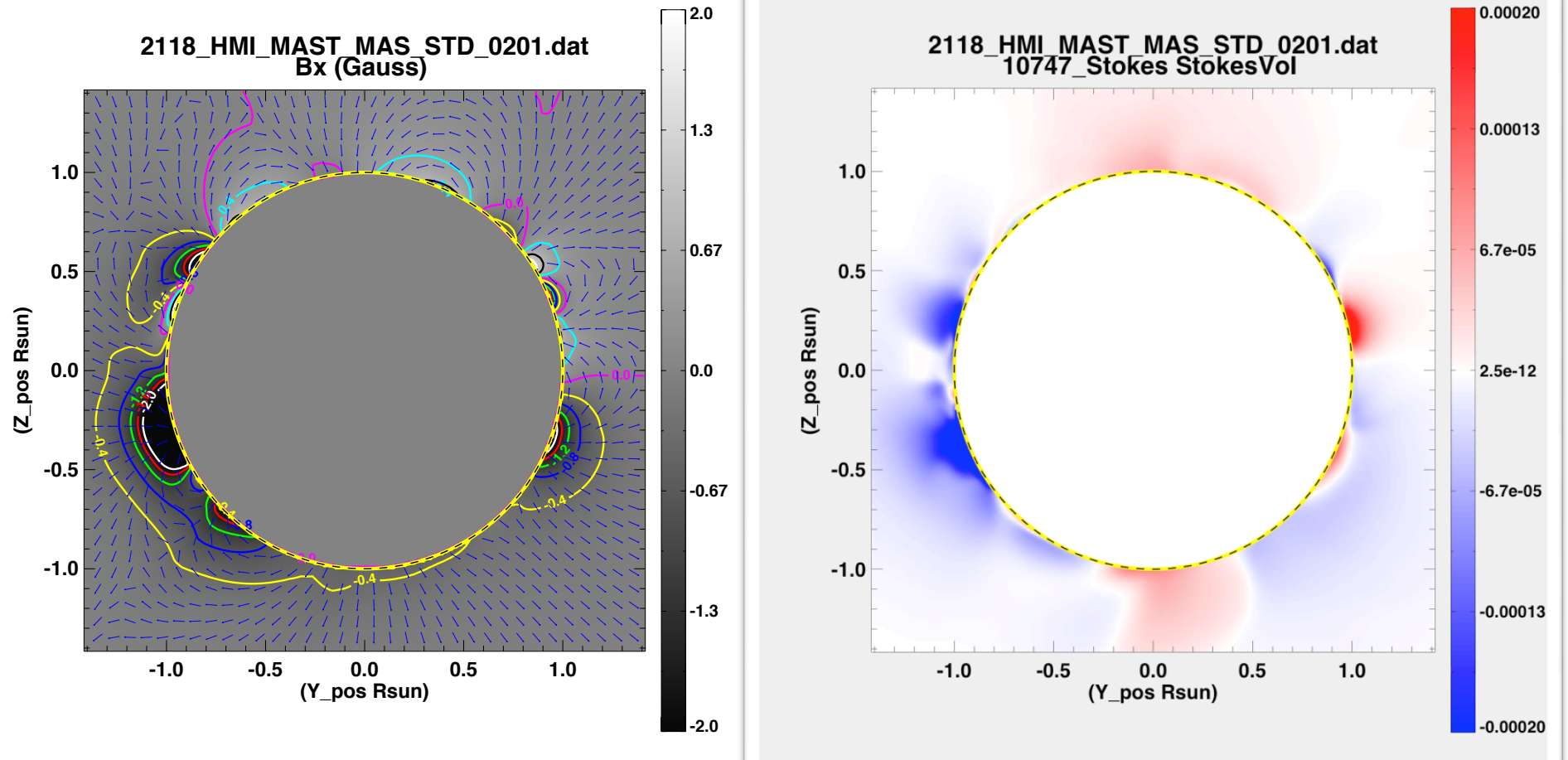# Model-data comparison

Line-of-sight field

Linear polarization

Stokes L=sqrt(Q^2+U^2) linear polarization

Using an analytic flux-rope model (Low and Hundhausen, 1995), we see that the presence of shear above the underlying neutral line narrows the ears and introduces the dark central head structure.
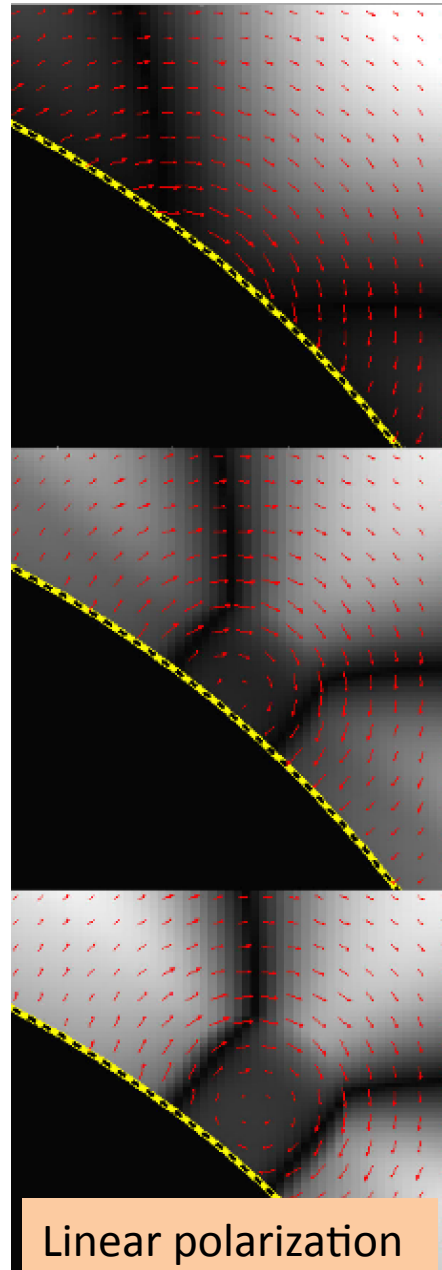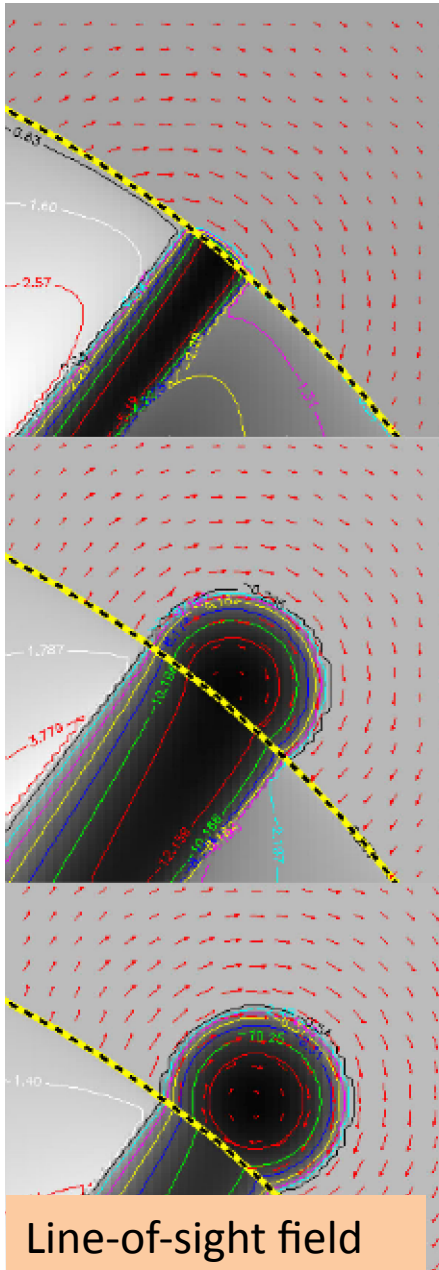
# Model-data comparison

Stokes V circular polarization

Circular polarization (Stokes V) shown here for the Fe13 10747 line gives a direct measure of line of sight magnetic field Bx. Line-of-sight integration results in an intensity-weighted Stokes V. This ambiguity can be resolved through measurements over several days.

Model-data comparison

Stokes V circular polarization
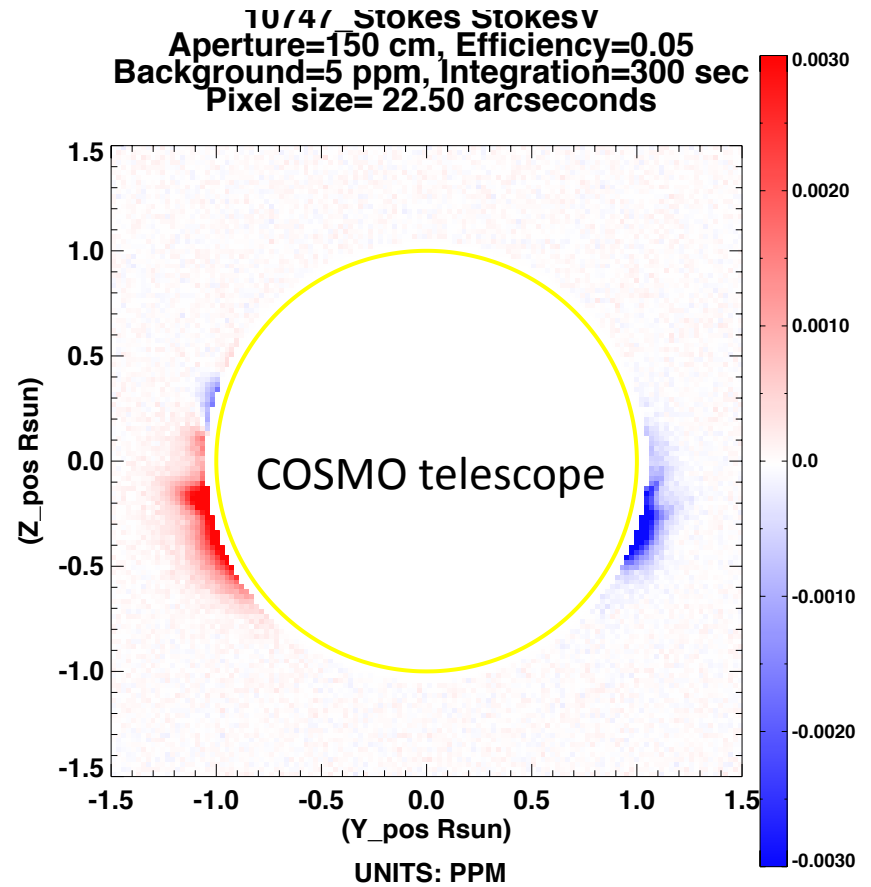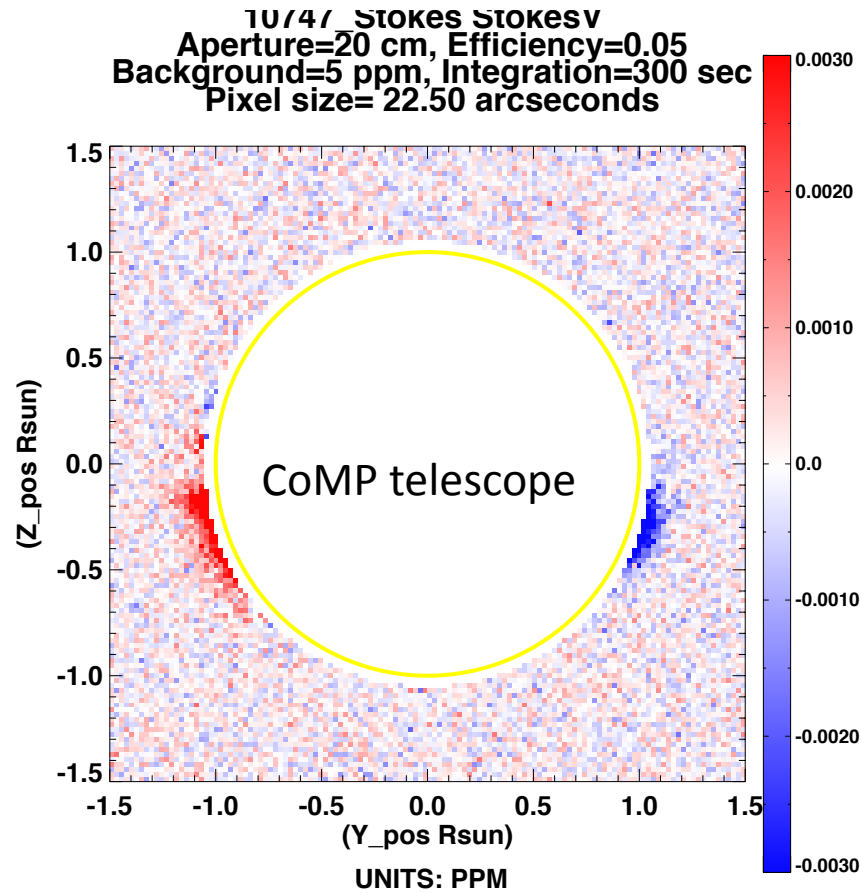
However- Stokes V signal is 1000 times dimmer than intensity in Fe13 10747. Given five minutes integration this demonstrates photon noise expected for MAS MHD coronal prediction, for a 20 cm (e.g. MLSO/CoMP) vs. a 150 cm (e.g. proposed COSMO) telescope. Note systematic errors are not included.

Model-data comparison

Stokes V circular polarization
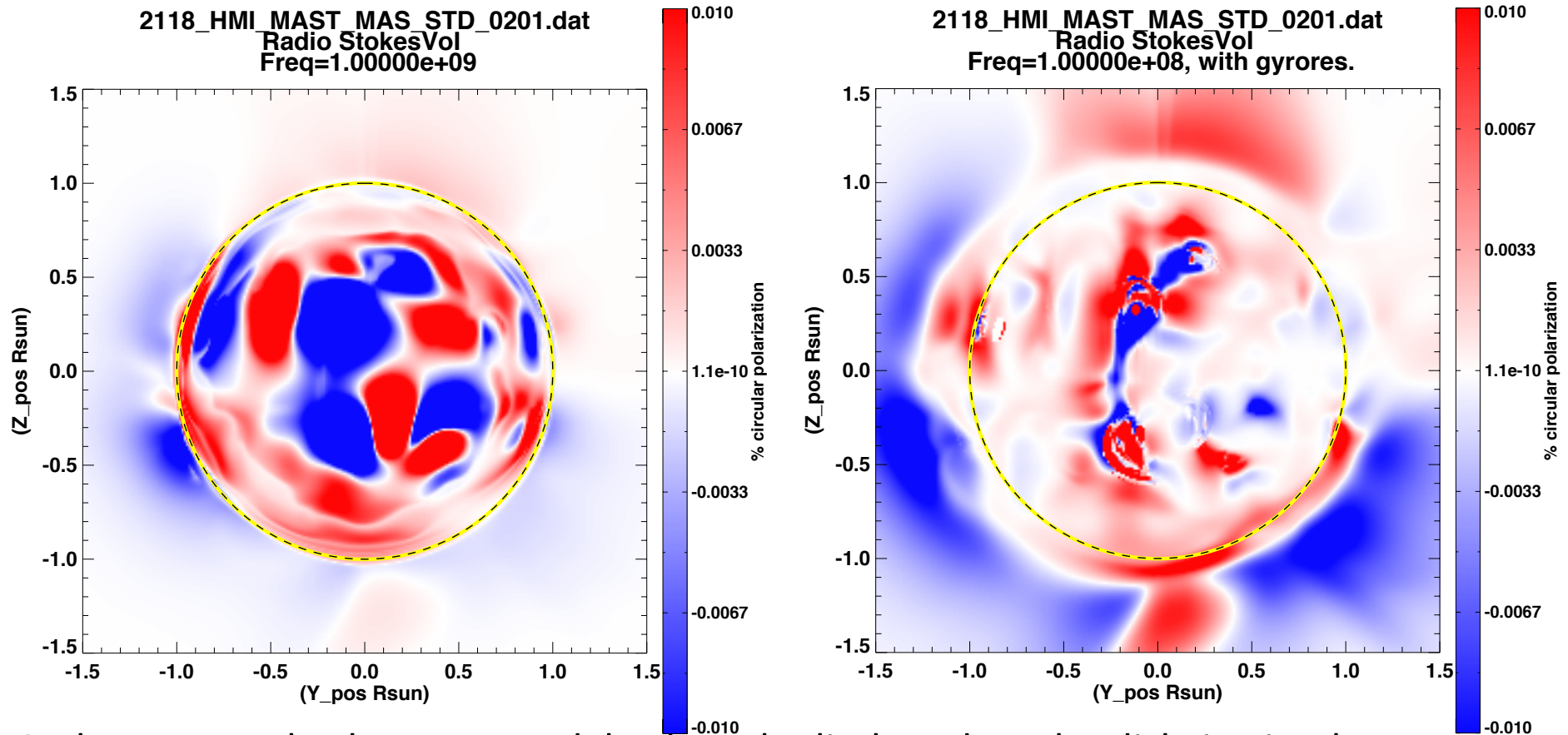
Stokes V may also be measured, both at the limb and on the disk, in circular polarization at radio wavelengths. When gyroresonance is included, radio probes optically-thick surfaces, at heights which vary with frequency. Comparing information from a broad range of spectral regimes may assist in probing the three-dimensional coronal magnetic field.

How to access FORWARD

You can download the latest version of FORWARD codes at:
http://people.hao.ucar.edu/sgibson/FORWARD/TARS/

Parent Directory -

Programs forward_jul27.tar 27-Jul-2014 11:14 2.3M

Database (big!) forwarddb_jan13.tar 21-Jan-2014 13:33 1.0G

Documentation forwarddocs_jul15.tar 15-Jul-2014 10:29 60M

Expand the tars to form three directories. You do an update by completely deleting old versions of these directories and expanding new tars.

Note that forwarddocs_[date].tar and forwarddb_[date].tar won't be updated as often. You can tell by [date] if you need to update them.

How to access FORWARD

The first time setting up FORWARD, you need to set IDL and system environments pointing to these directories, and include some SolarSoft packages.

If you are running the *CLE* Fortran77 interface (for coronal polarimetry) you will need a Fortran compiler with which to compile a local executable. You can do this once and keep it in a (system-environment defined) working directory.

Details on how to do these steps for Mac/Unix and PC/Windows platforms can be found here:

http://people.hao.ucar.edu/sgibson/FORWARD/
FORWARD_DOCS/INSTRUCTIONS/installupdate.html

Published papers utilizing FORWARD

Gibson, S. E., Coronal cavities: Observations and implications for the magnetic environment of prominences, chapter in Solar Prominences, O. Engvold and J.-C. Vial eds., Springer, in press, 2014**.**

Rachmeler, L. A., Platten, S. J., Bethge, C., Seaton, D. B., Yeates, A. R., Observations of a hybrid double-streamer/pseudostreamer in the solar corona, ApJL, 787, 2014

Bak-Steslicka, U., Gibson, S. E., Fan, Y., Bethge, C., Forland, B., and Rachmeler, L., The magnetic structure of solar prominence cavities: new observational signature revealed by coronal magnetometry, ApJL, 770, 28, 2013.

Rachmeler, L. A., Gibson, S. E., Dove, J., DeVore, C. R., and Fan, Y., Polarimetric observational properties of flux ropes and sheared field in the corona, Topical Issue in Solar Physics on Coronal Magnetism, 288, 61, 2013.

Gibson, S. E., Magnetism and the Invisible Man: the secrets of coronal cavities, Proceedings IAU Symposium No. 300, B. Schmieder, J.-M. Malherbe and Shi Wu, eds., 2013

Forland, B., Gibson, S., Dove, J., and Kucera, T., The solar physics FORWARD codes: Now with widgets! Proceedings IAU Symposium No. 300, B. Schmieder, J.-M. Malherbe and Shi Wu, eds., 2013.

Rachmeler, L. A., Casini, R., and Gibson, S. E., Interpreting coronal polarization observations, ASP conference series, 2012.

Kucera, T. A., Gibson, S. E., Schmit, D. J., Landi, E., and Tripathi, D., Temperature and EUV intensity in a coronal prominence cavity, ApJ, 757, 73, 2012.

Reeves, K. K., Gibson, S. E., Kucera, T. A., Hudson, H. S., Thermal properties of coronal cavities observed with the X-ray telescope on Hinode, ApJ, 746, 146, 2012.

Schmit, D. J. and Gibson, S. E., Forward modeling cavity density: a multi-instrument diagnostic, ApJ, 733, 1, 2011

Dove, J. B., Gibson, S. E., Rachmeler, L. A., Tomczyk, S., and Judge, P., Coronal magnometry: Observational signatures of magnetic flux ropes, ApJ Letters, 731, 1, 2011

Gibson, S. E., Kucera, T. A., Rastawicki, D., Dove, J., de Toma, G., Hao, J., Hill, S., Hudson, H. S., Marque, C., McIntosh, P. S., Rachmeler, L., Reeves, K. K., Schmieder, B., Schmit, D. J., Seaton, D. B., Sterling, A. C., Tripathi, D., Williams, D. R., Zhang, M., Three-dimensional morphology of a coronal prominence cavity, 724, 1133, ApJ, 2010

Future FORWARD

- **FORWARD** has been extensively beta-tested, and is now ready to be submitted as a SolarSoft package – this will make installing and updating easier

- New capabilities for UV spectropolarimetry are currently being tested

- New capabilities for better interface with varied-grid numerical models are being considered

- Development of "instrument personality profiles" may be crucial for using **FORWARD** as a planning tool for the design and use of future large telescopes such as DKIST, COSMO, and FASR.