CORONAL MAGNETOMETRY WITH THE "GREEN LIGHT"

SOLARNET SPRING SCHOOL

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WROCŁAW, POLAND

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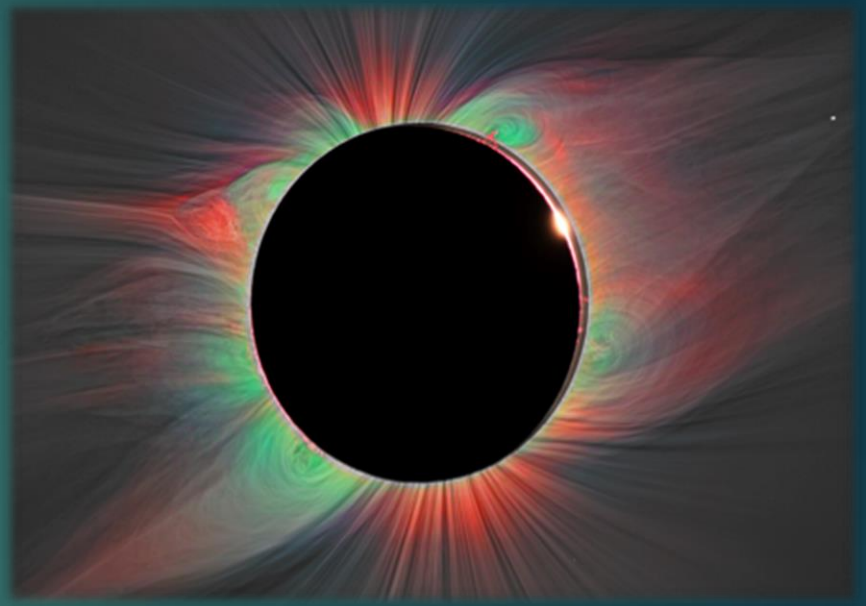
What's the solar corona?

- The corona is the outermost part of the Sun atmosphere.
- Before the space age, the observation of the solar corona was possible only during solar eclipses and through the use of coronagraphs.
- Its temperature is of the order of 10^6 K.
- Its appearance shows systematic variations with the solar cycle.

M. Druckmuller , Solar corona (July 2010)

Coronal optical radiation components

- CORONA K (Kontinuum): dominates at small distances from the edge, its spectrum is flat and has an intense linear polarization. It is photospheric radiation diffused by Thompson scattering from electrons present in corona.
- CORONA F (Fraunhofer): dominates at higher distances from the disk (about 2-3 solar radii). The spectrum shows Fraunhofer lines and the radiation is not polarized. The F corona is due to Mie diffusion of solar radiation by dust particles.
- CORONA E (Emission): due to atomic emission processes resulting in spectral lines. These ones are lines of high order ions and the more intense are the 'green line' (FeXIV), the 'red line' (FeX), the 'yellow line' (CaXV) and the 'infrared' line (FeXIII).



Habbal et al., ***an overlay of white light, Fe XIV 530.3 nm (green), and Fe X 637.4 nm (red) emission from observations taken during the total solar eclipse of 1 August 2008.***

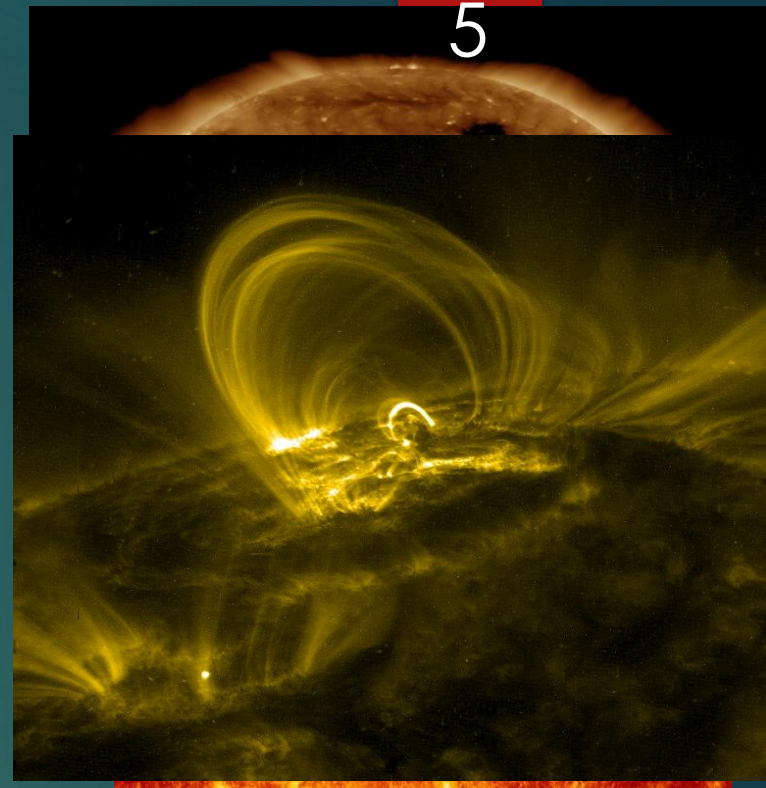
Spectroscopy of solar corona

- Coronal emission lines are produced by ions that had been excited to a superior state by **collisions** with electrons and **absorption of photons.**
- These emission lines can be formed only at certain temperatures, and therefore their individuation in solar spectra is a strong indication of the emitting plasma temperature .
- Coronal emission lines are 'forbidden' because they came from transitions between energy levels belonging to the same configuration.

Characteristic phenomena of the corona

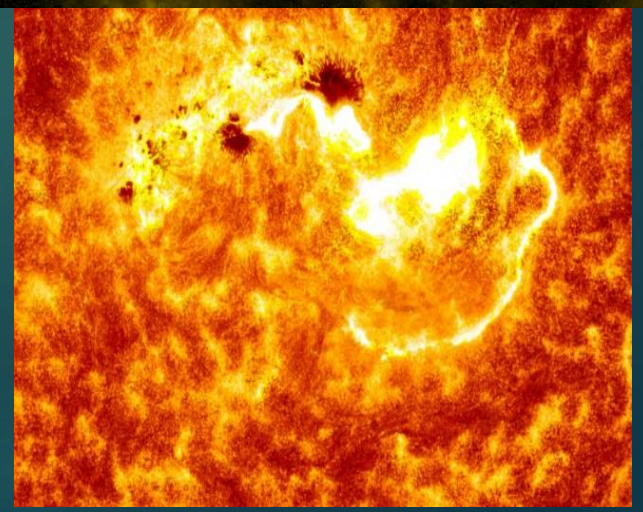
The solar corona is characterized by different patterns:

- CORONAL HOLES: areas with no X-ray emission, concentrated at the poles which may extend to the equator. They bound lines of force of the open magnetic field from which solar wind emerges.
- CORONAL LOOPS: structures associated with the closed magnetic field lines that connect magnetic regions on the solar surface.
- FLARE: explosive phenomenon that occurs in the solar atmosphere and affects all regions of the electromagnetic spectrum. Its most evident manifestation is the increase in brightness due to magnetic reconnection → prominence eruption / CMEs



Coronal hole

Coronal loops



Flare

Open questions about corona

- What are the mechanisms underlying its heating?

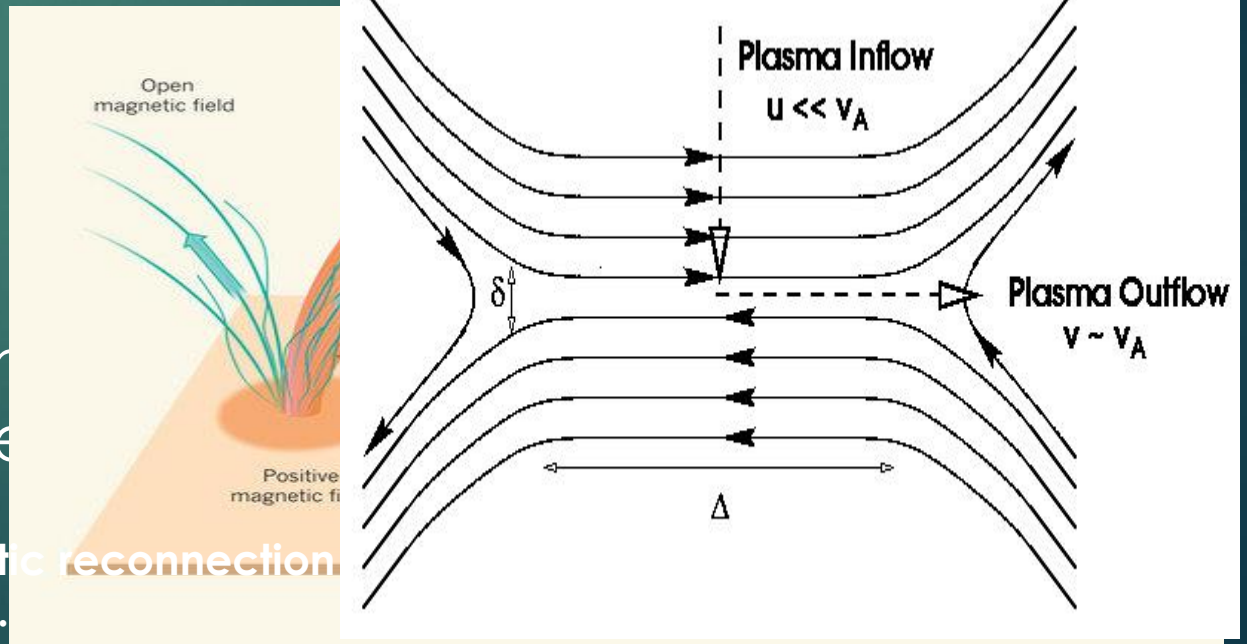
The fact that corona is hotter than the photosphere indicates that there must be physical mechanisms able to deposit energy in this layer.

Among the physical mechanisms proposed there are :

→ ALFVEN WAVES

→ MAGNETIC RECONNECTION

Unfortunately good knowledge of th
good determination of coronal magne



Alfvén waves in two coronal geometries.

Magnetic reconnection pattern.

How to obtain quantitative measurements of the coronal magnetic field?

For the most part the magnetic field governs the shape and the dynamics of the solar corona. Coronal images in the visible, ultraviolet and X-rays are able to give qualitative information about the topology of such large-scale fields.

Techniques used for the determination of the magnetic fields are:

→ EXTRAPOLATION OF CORONAL MAGNETIC FIELDS THROUGH PHOTOSPHERIC MAGNETOGRAM (indirect method).

- Approximation FORCE-FREE
- Approximation CURRENT-FREE

→ THE MEASUREMENT OF THE POLARIZATION OF CORONAL EMISSION LINES (direct method).

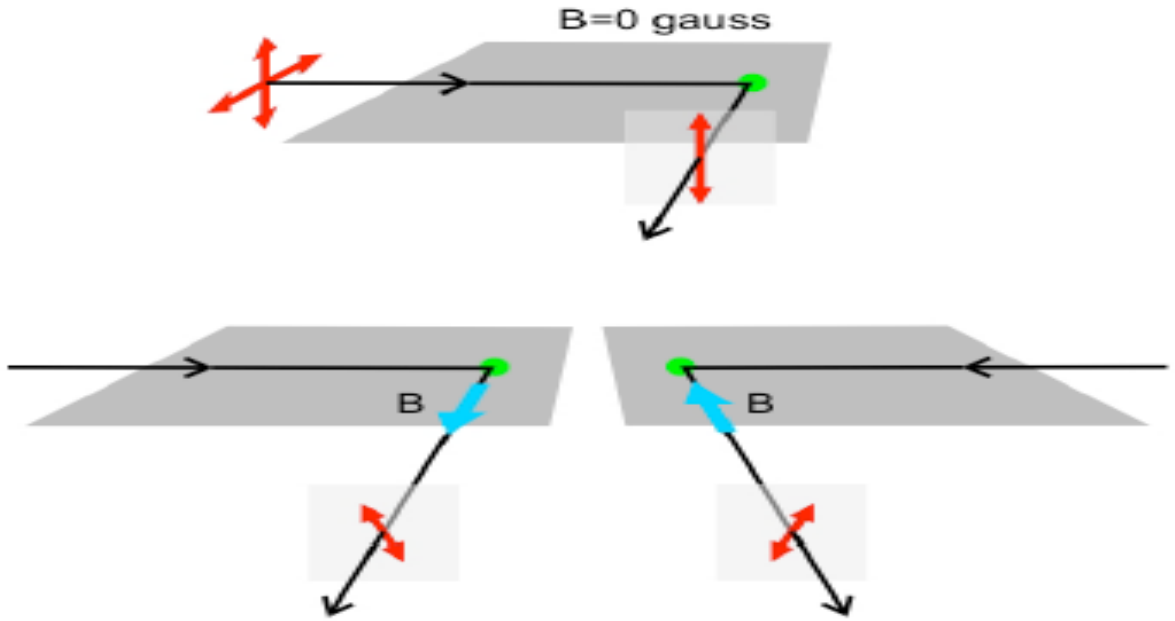
Objectives of my research project

- The study of the solar corona magnetic field through the data reduction and analysis of the polarimetric observations of the forbidden emission-line of FeXIV, carried out during the solar eclipse of 2010;
- The interpretation through the Hanle effect of the linear polarization of the "green line" for the diagnostic of coronal magnetic field topology.
- Comparison between observations and numerical simulations with FORWARD code developed by the High Altitude Observatory.

Hanle Effect

The impact of the Hanle effect on the linear polarization produced by scattering processes

90° scattering geometry



If $\omega_{Larmour} >> A_{ul}$ (VIR forbidden lines)

The Hanle effect REDUCES the amplitude of the line scattering polarization signal

(i.e., Stokes Q decreases with respect to the B=0 G case) !

The Hanle effect ROTATES the direction of linear polarization

(i.e., Stokes U is NON-ZERO) !

⇓

P is // or ⊥ **B**

Critical Hanle field?

$8.79 \times 10^6 \, g_L \, B(gauss) \sim 1/Lifetime$

Magnetic splitting of the Level = Natural width of the Level

The van Vleck Effect

- *LP changes sign at $3\cos^2\theta_{vv} - 1 = 0$*

- If the angle of the magnetic field with respect to normal to photosphere is larger or smaller 54.7 degree, Stokes LP will change its sign.

- *Van Vleck Angle*

  $\theta_{vv} = 54.7$ deg

  $\Psi = \theta_{vv}$, light becomes unpolarized.

  $\Psi < \theta_{vv}$, then LP // ***B***

  $\Psi > \theta_{vv}$, then LP ⊥ ***B***

Hanle effect
$\omega_{Larmour} >> A$

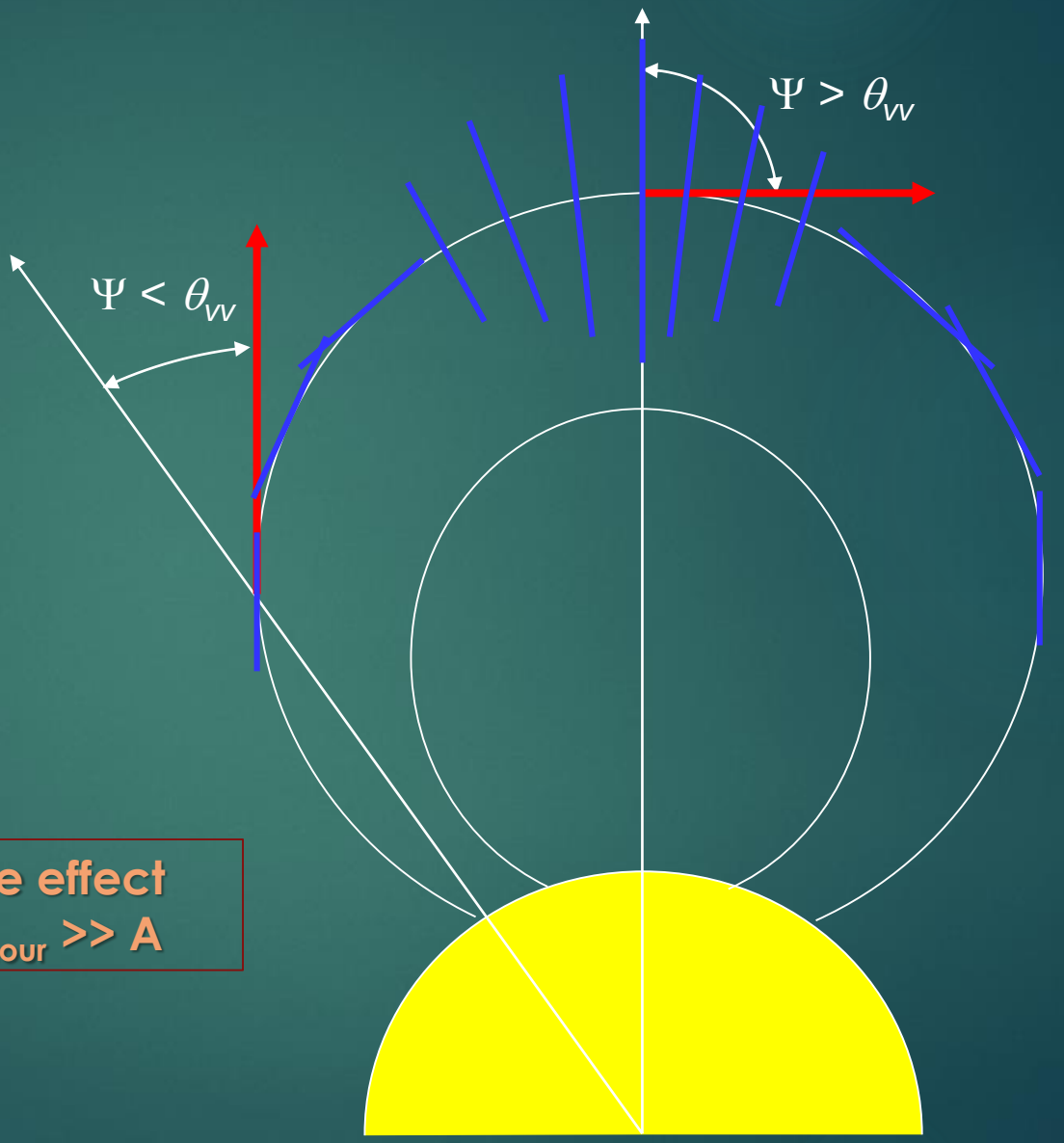
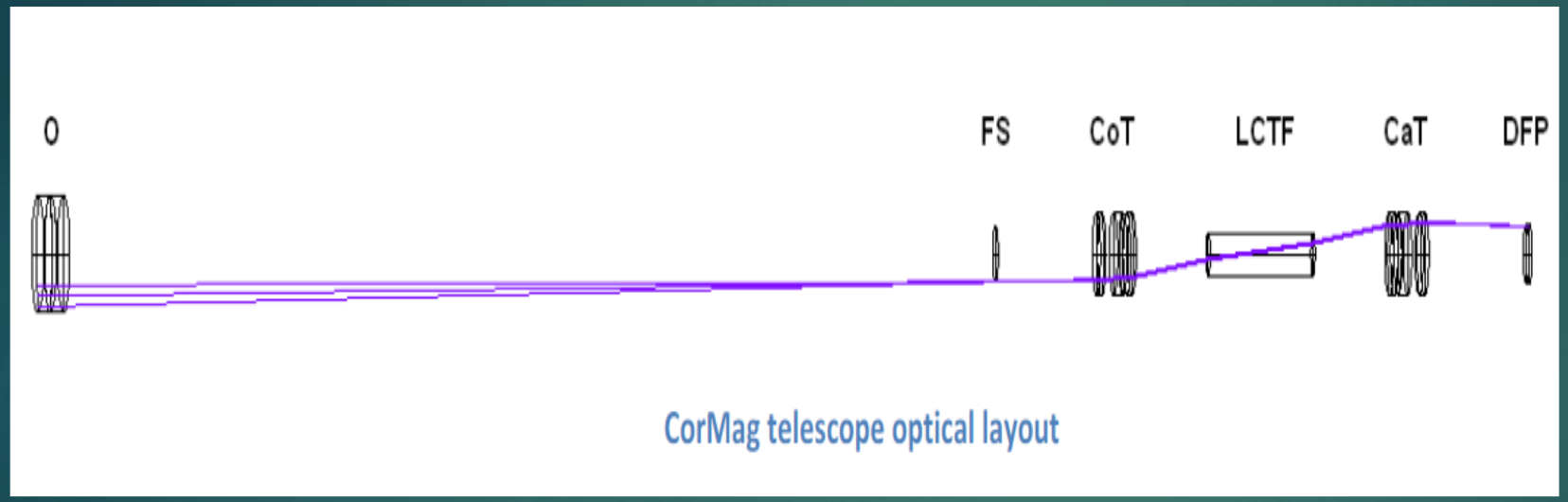


Figure taken from H. Lin presentation for SOLAR-C meeting

Linear polarization direction

Instrumentation

Polarimetric images used for the study of polarization have been acquired by the INAF-TURIN spectropolarimeter telescope 'Cormag' during the Total Solar Eclipse of July 11th 2010 in Tatakoto Atoll (French Polynesia).



CorMag telescope optical layout

1024X1024 pix, 16 bit/pix, 2MB per image, pix 24μm, 6.2''/pix
Images acquired with a Liquid Cristal Tunable Polarimeter around the FeXIV 530.3nm
31 exposures (exptime 8 sec): 21, 5 and 5 with pol. angles 0°, 60° and 120° (respectively)

Forward modelling

Through the forward modelling is possible calculate simulated polarization signals from a theoretical magneto-hydrodynamic model and then compare these images with observations.

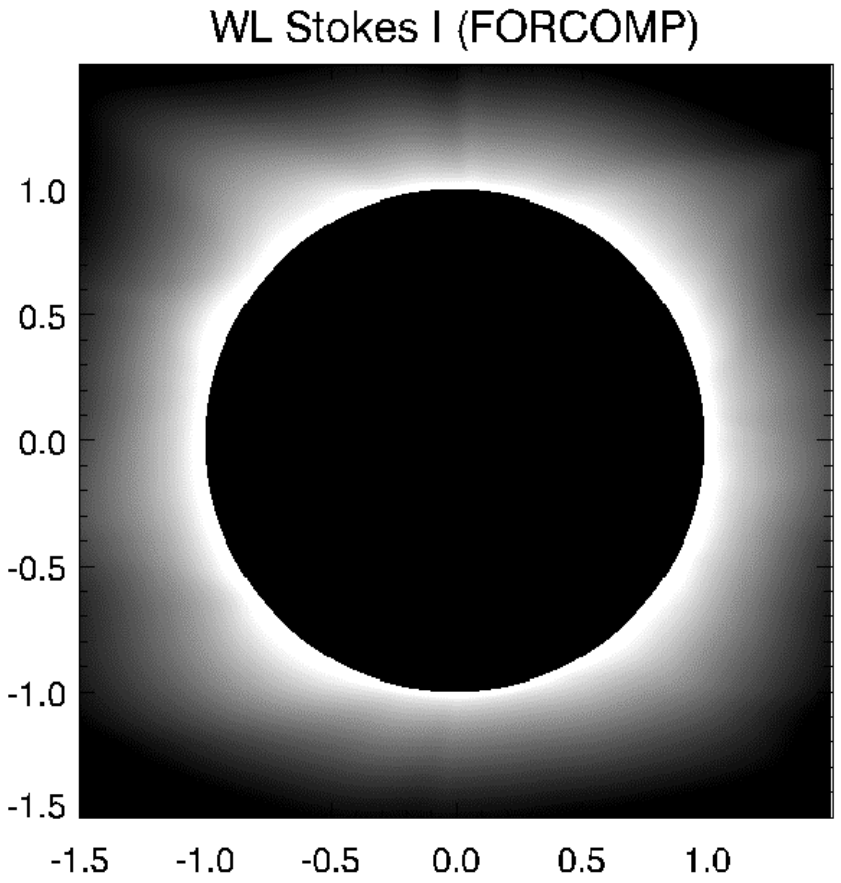
The basic procedure of forward technique is:

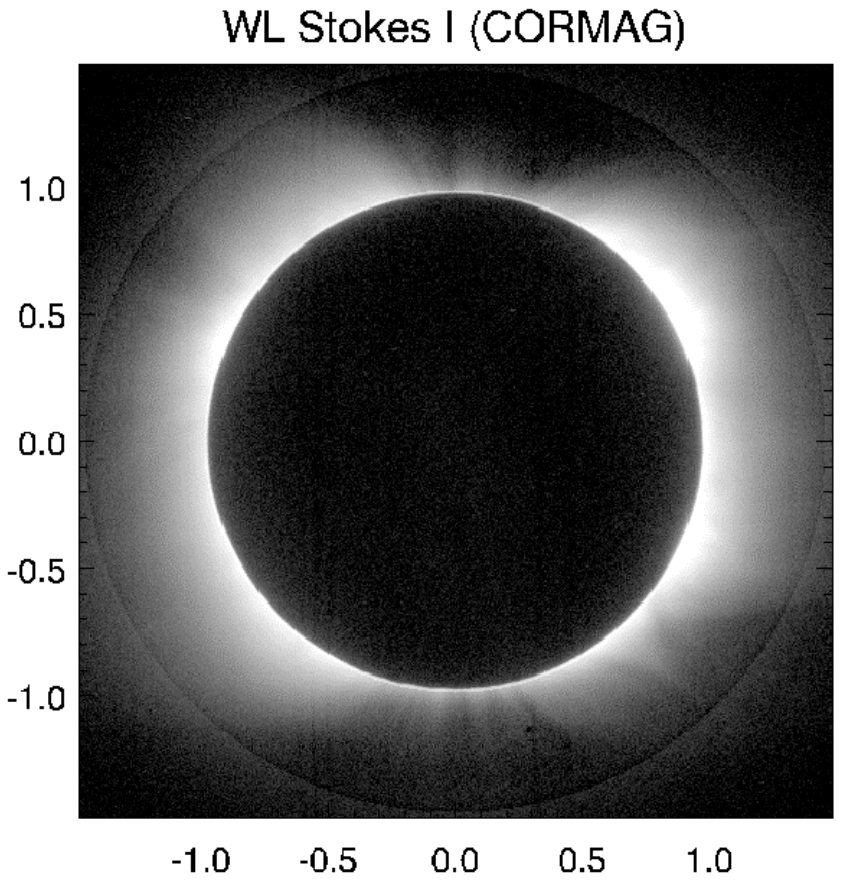
- At first determination of the Stokes vector along a given LOS;
- Secondly, computation, through the Fortran code FORCOMP, of the level populations and emitting polarization profile of Fe XIV transition at each location;
- Then FORCOMP calculates the polarization of reemitted radiation in the direction of the observer;
- Finally signals are then integrated over wavelength into a single number for each pixel and assembled into an image.

From 'Properties of Flux Ropes and Sheared Arcades in Coronal Prominence Cavities'- L.A. Rachmeler ·S.E. Gibson · J.B. Dove · C.R. DeVore ·Y. Fan

First results…

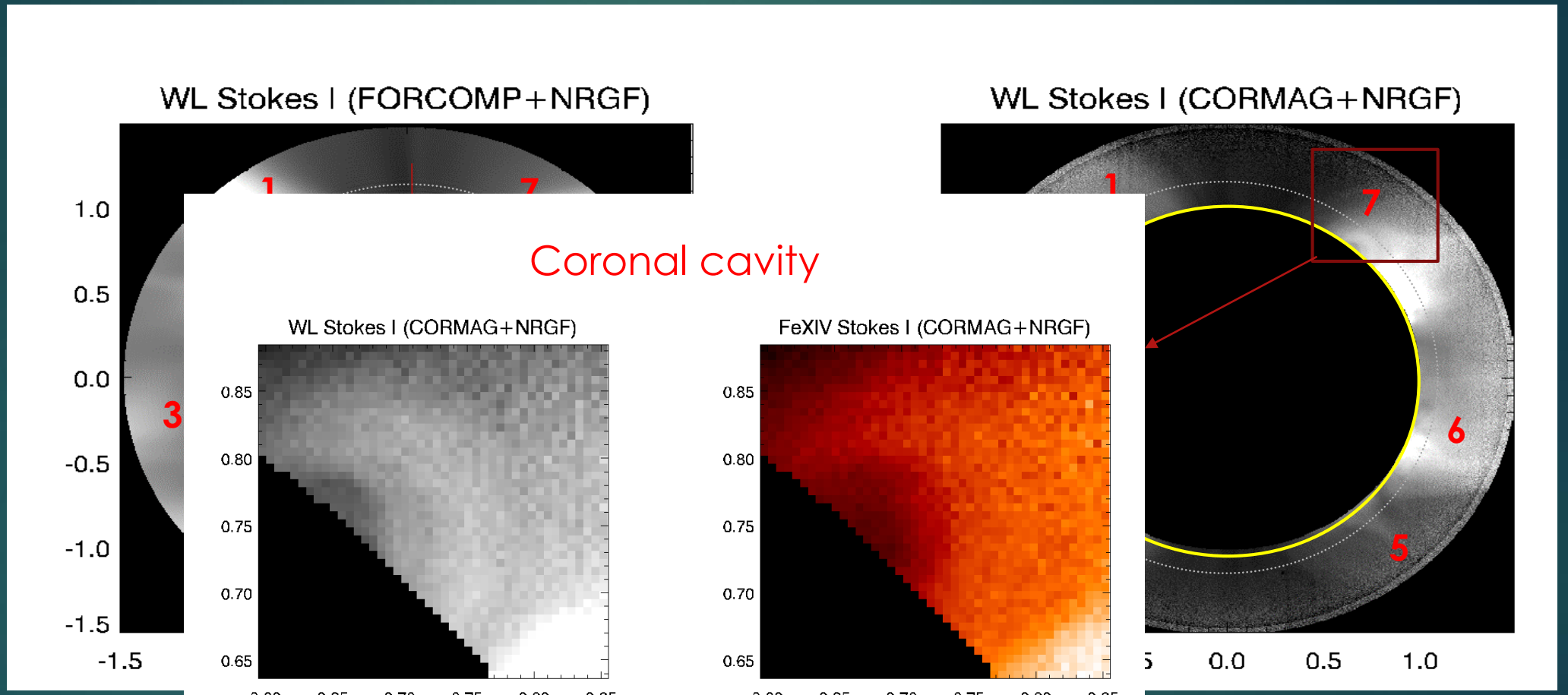
WL emission (K-corona, unpolarized)





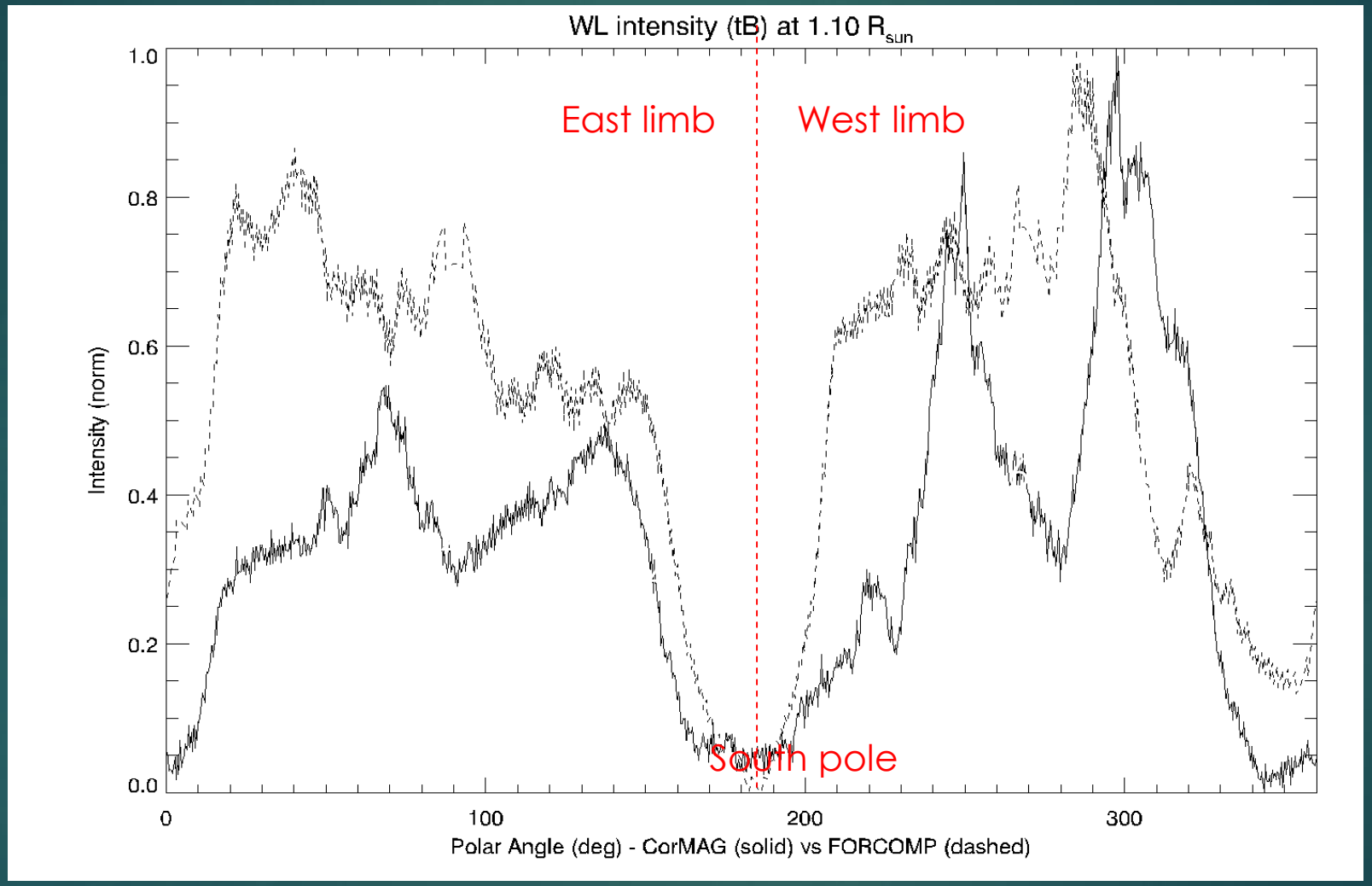
Significative differences already present in WL unpolarized light distribution.

WL emission (K-corona, unpolarized, NRGF)



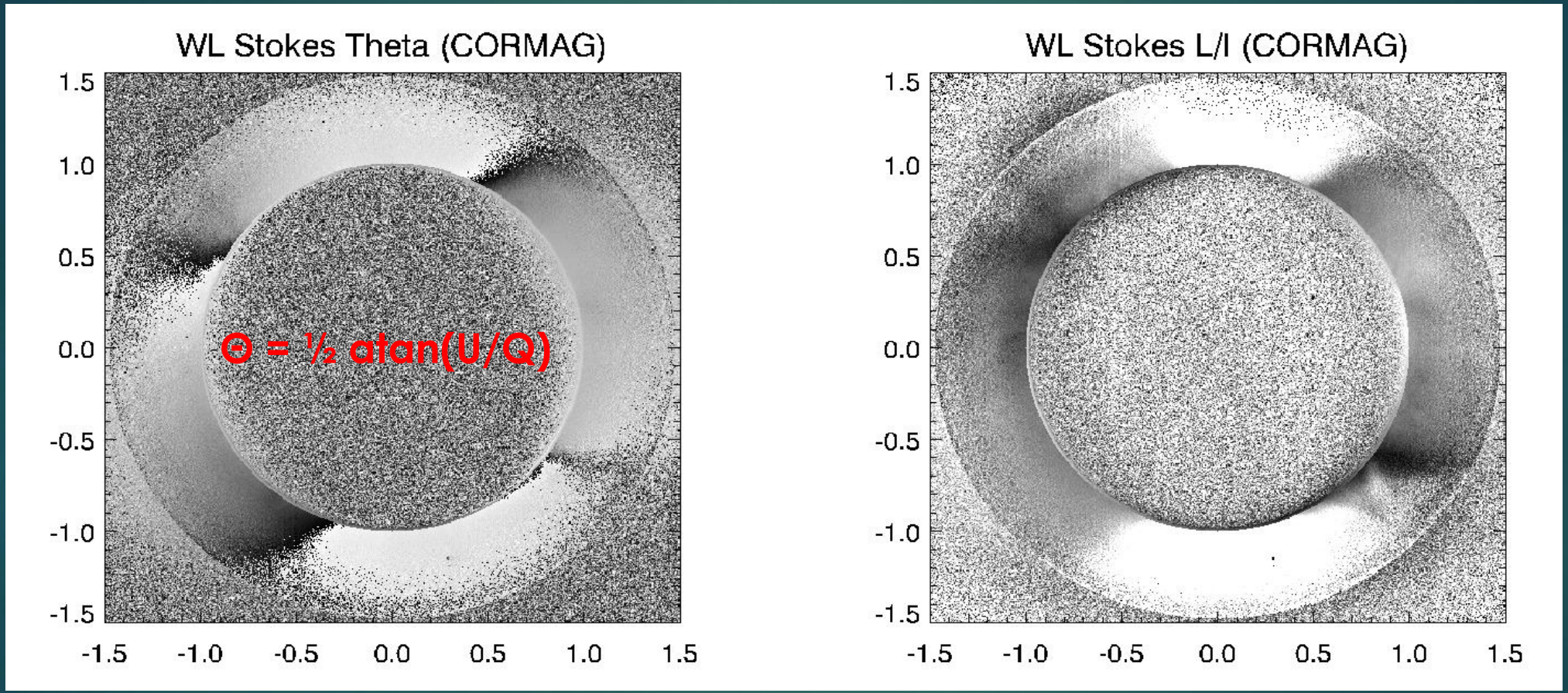
Significative differences alreday present in WL unpolarized light distribution.

WL emission (K-corona, unpolarized) at 1.1 R_{sun}



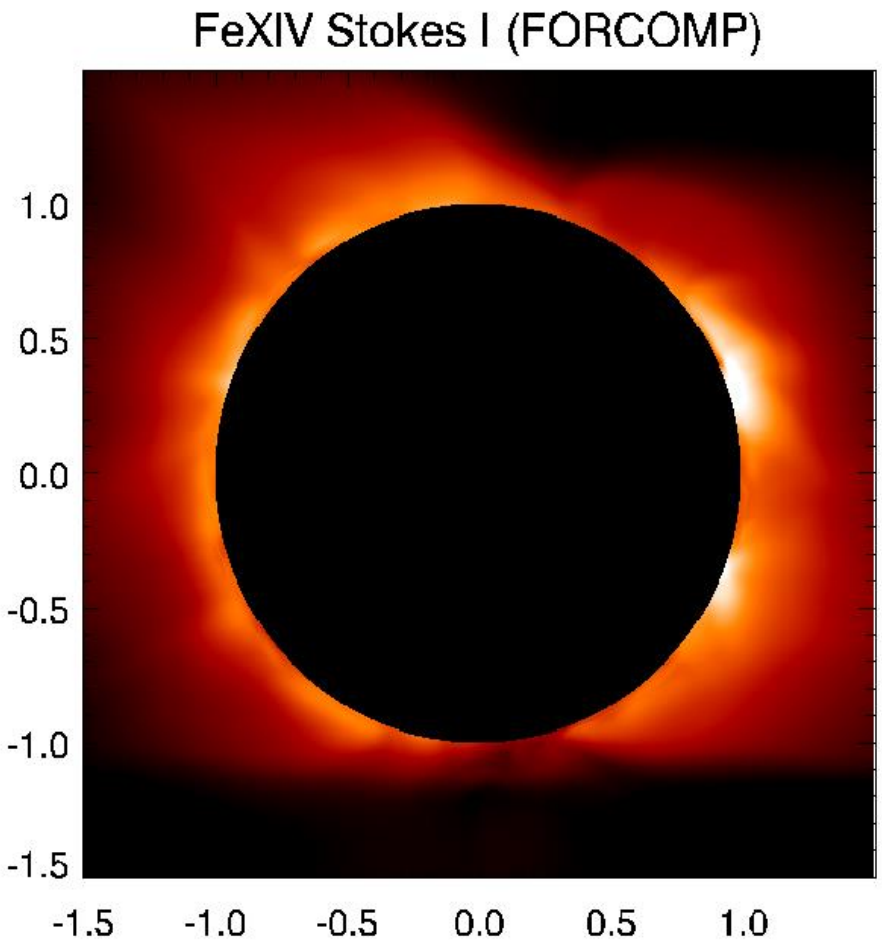
Significative differences already present in WL unpolarized light distribution.

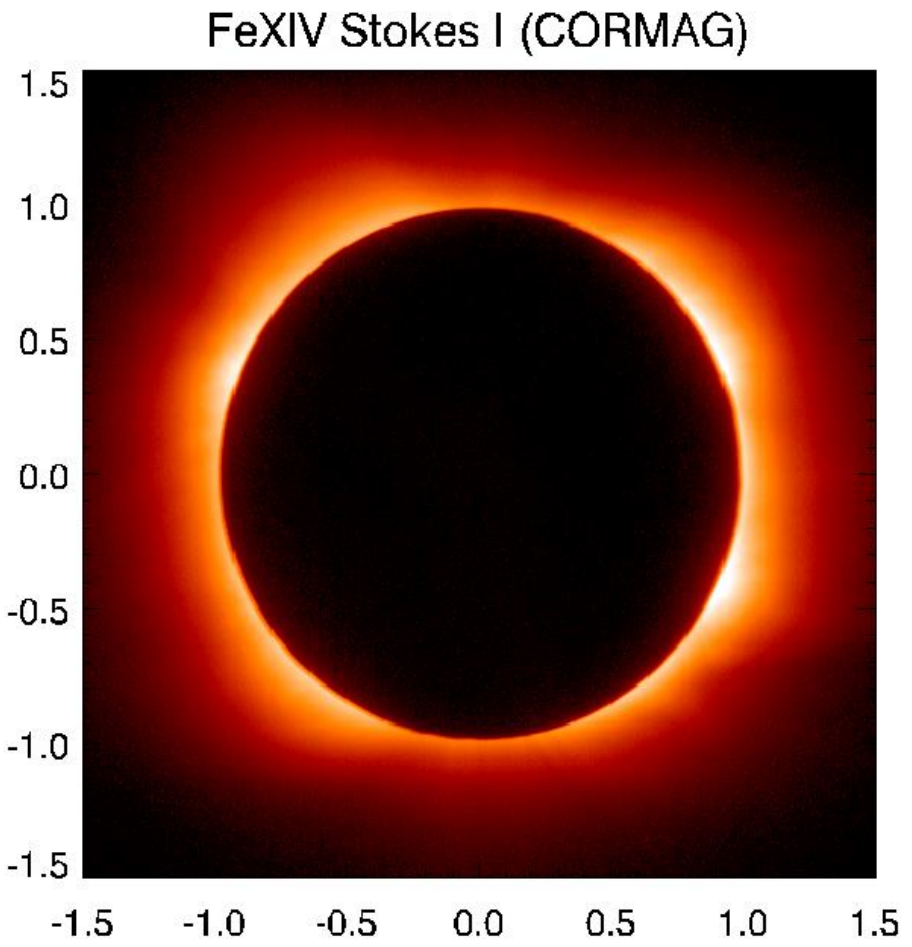
WL emission (K-corona)



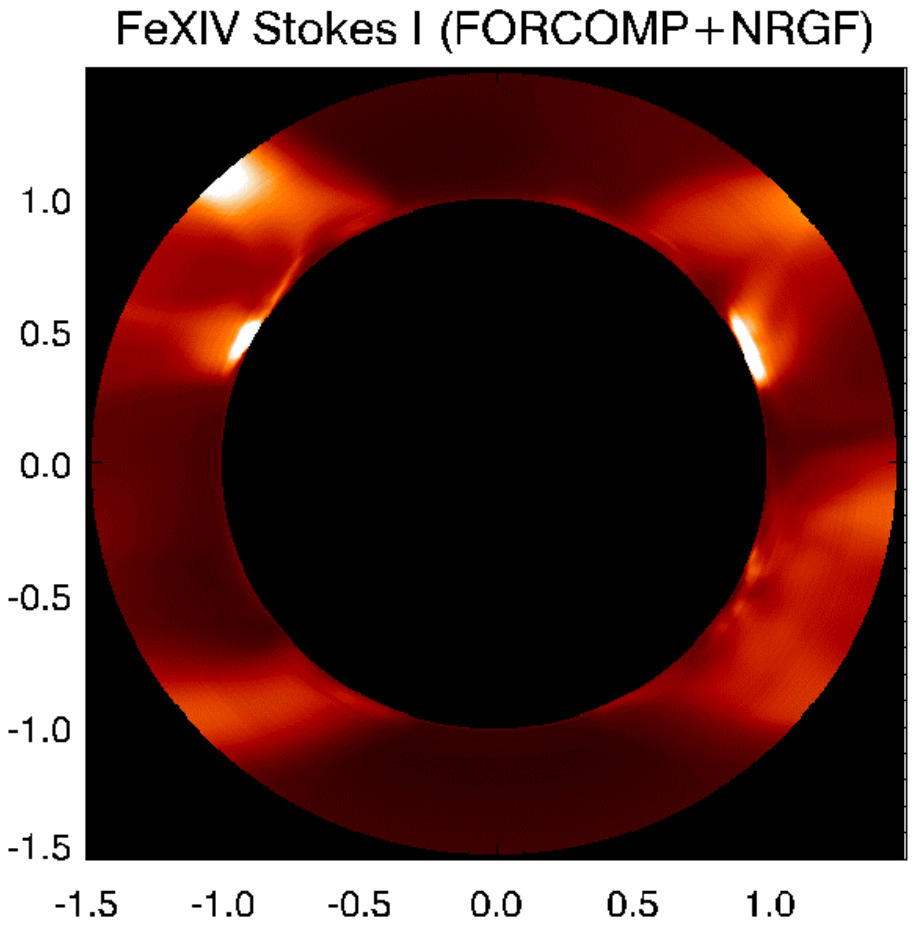
Background correction for clouds is already quite good, but still need to be improved.

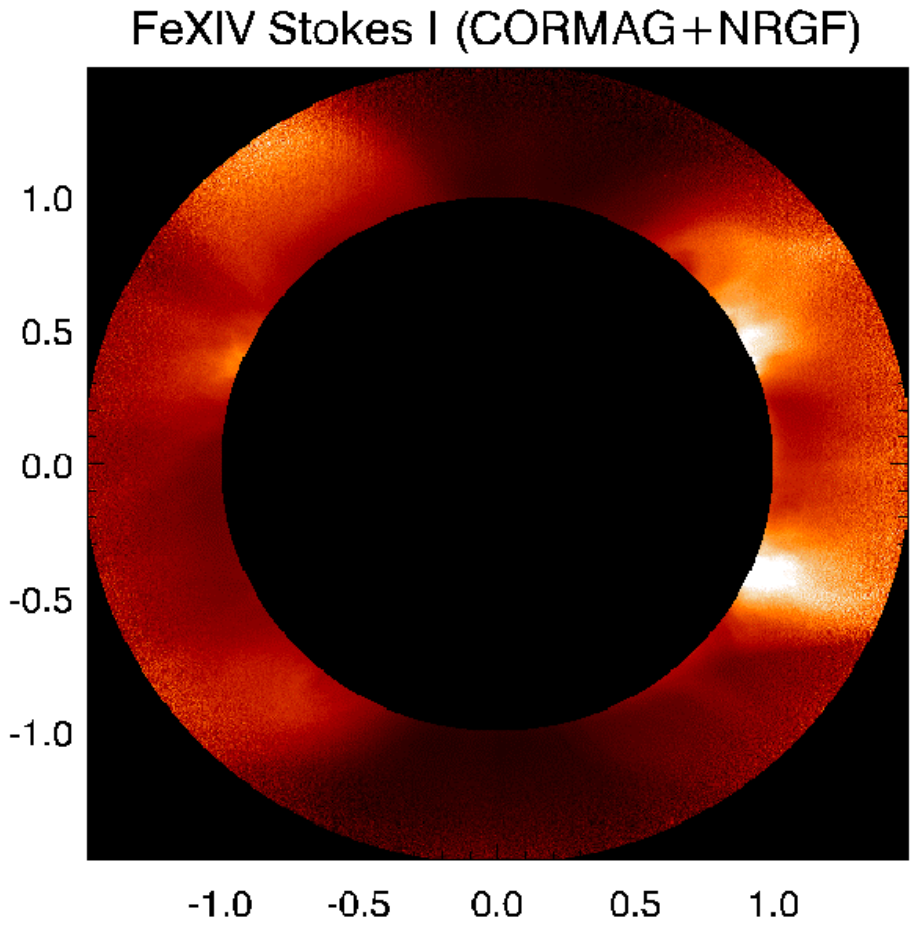
WL emission FeXIV (E-corona, polarized)



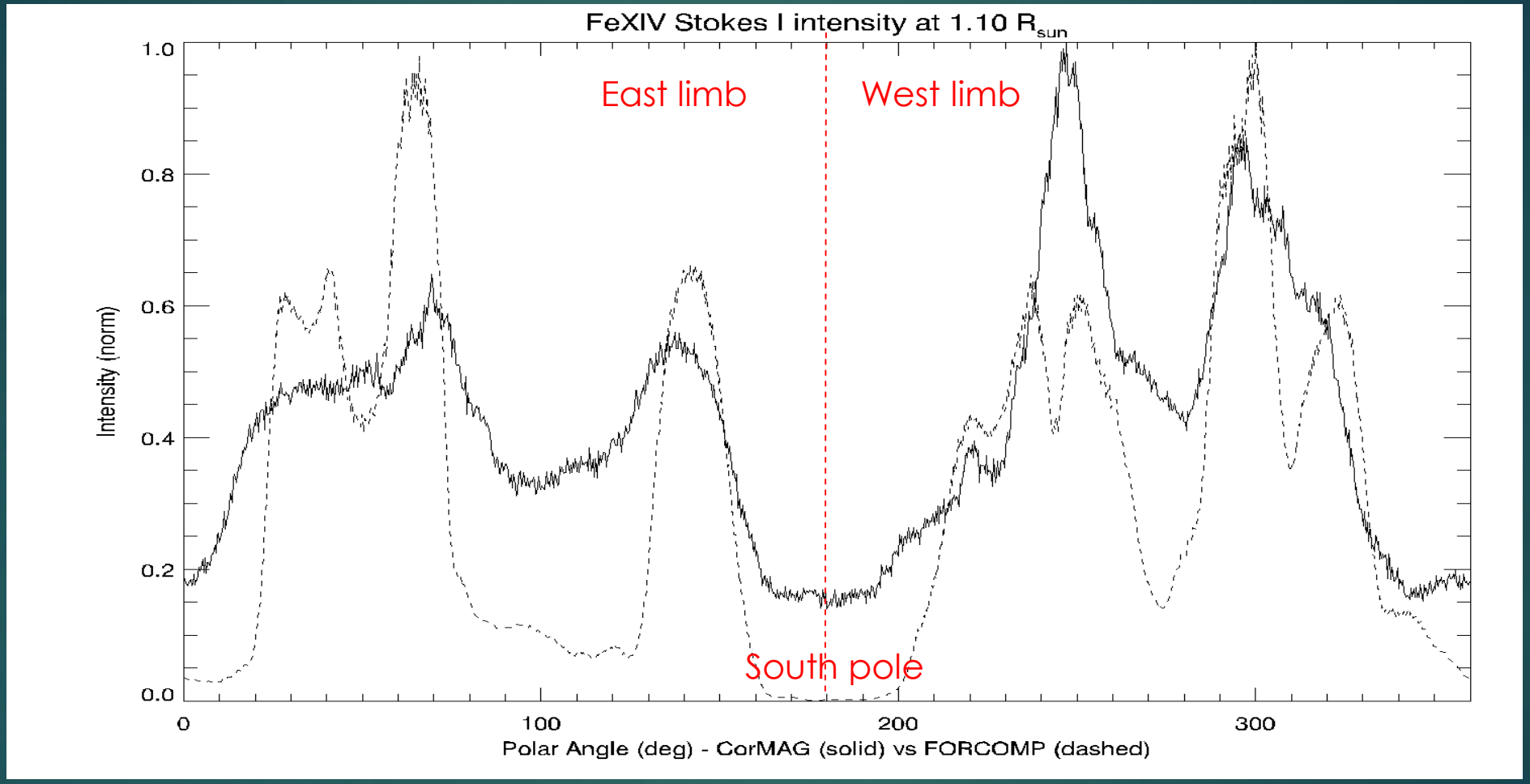


WL emission FeXIV (E-corona,polarized, NRGF)

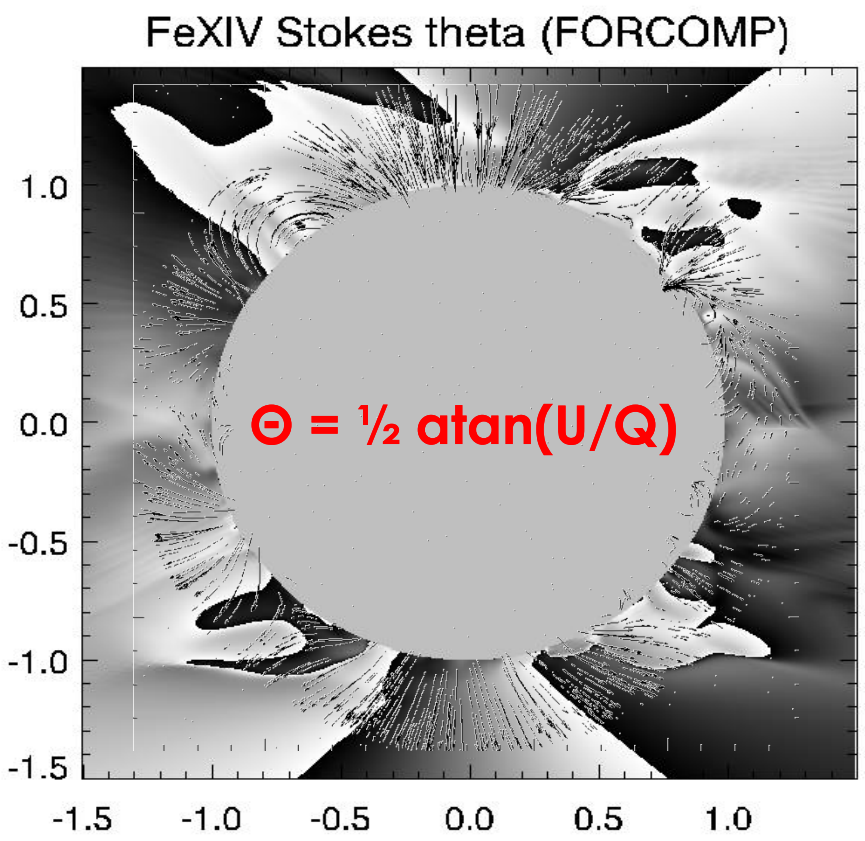


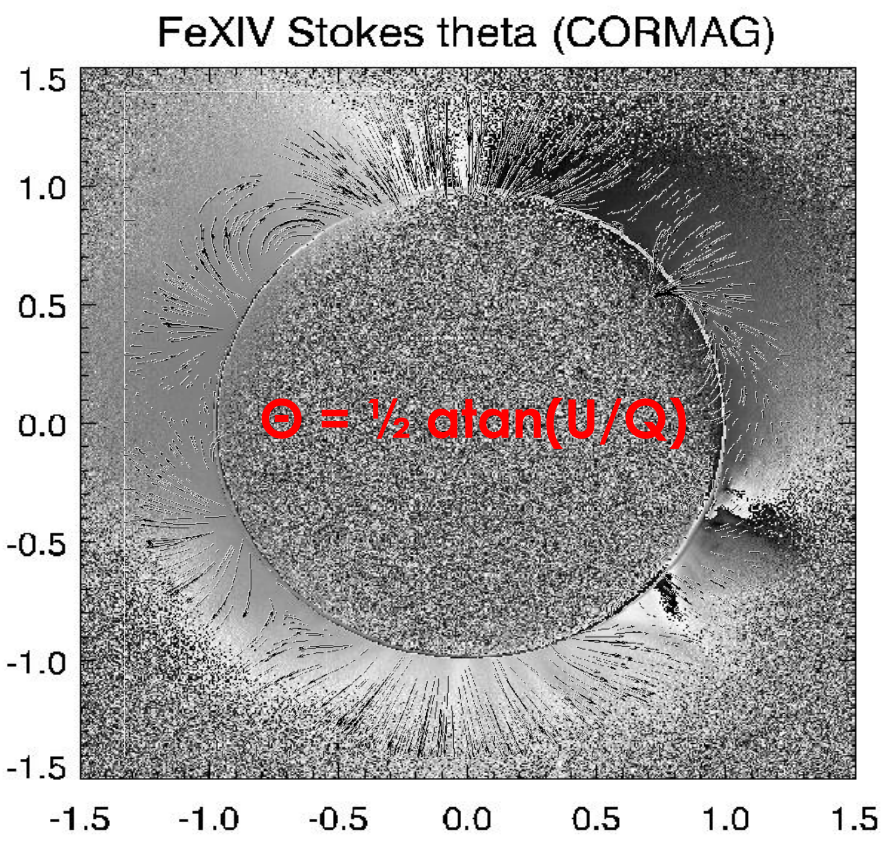


WL emission (E-corona, polarized) at 1.1 R_{sun}



WL emission FeXIV (E-corona, polarized)





Required for progresses

- Fine centring correction of the eclipse images;
- Better correction for cloud removal;
- Comparison between simulated magnetic field and observed Stokes' vector→ similarities/differences between theoretical and observed field (Hanle effect).
- Is the theorethical magnetic ' force free' model exact?→ Extrapolated photopheric magnetic field is not instantaneus but averaged over the observational time of the magnetogram →

  it doesn't rapresent the exact situation at the observation time.
- Post-eclipe calibration of the Cormag instrument.

↓

- These expertises will be a starting point for analysis of polarized data that the Team will acquire daily at Lomnycki Stit coronagraph.

Thank you for the attention.