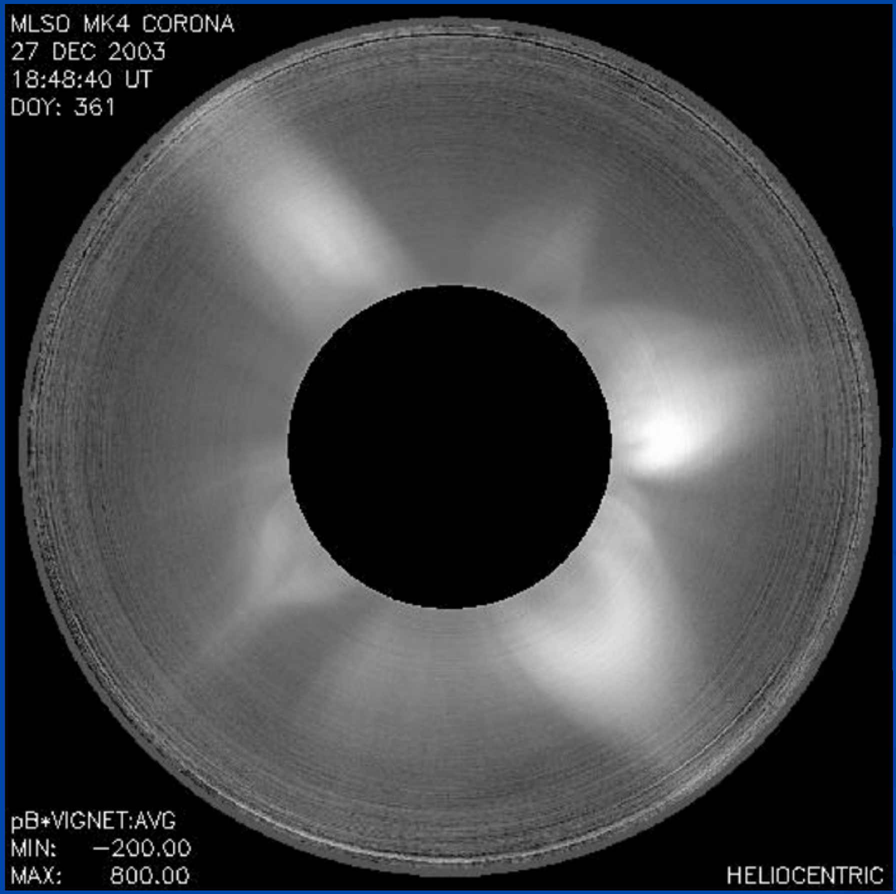
Observing the Unobservable? Modeling coronal cavities to determine cavity densi

Jim Fuller



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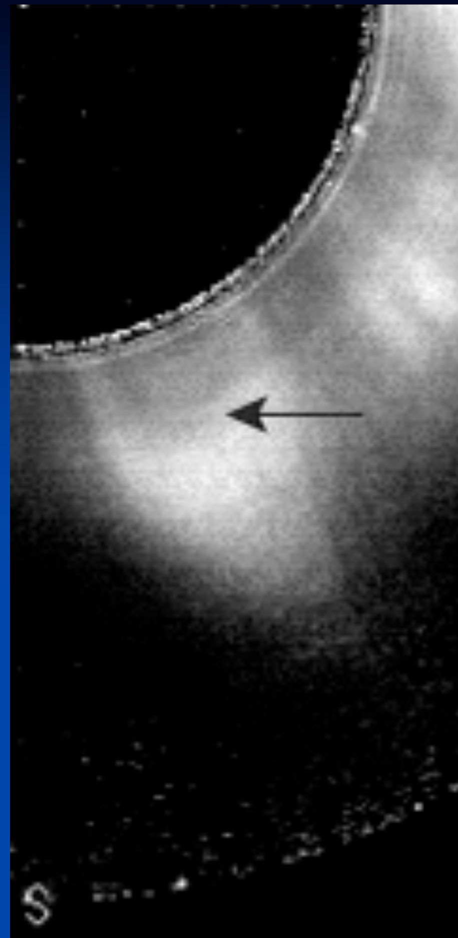
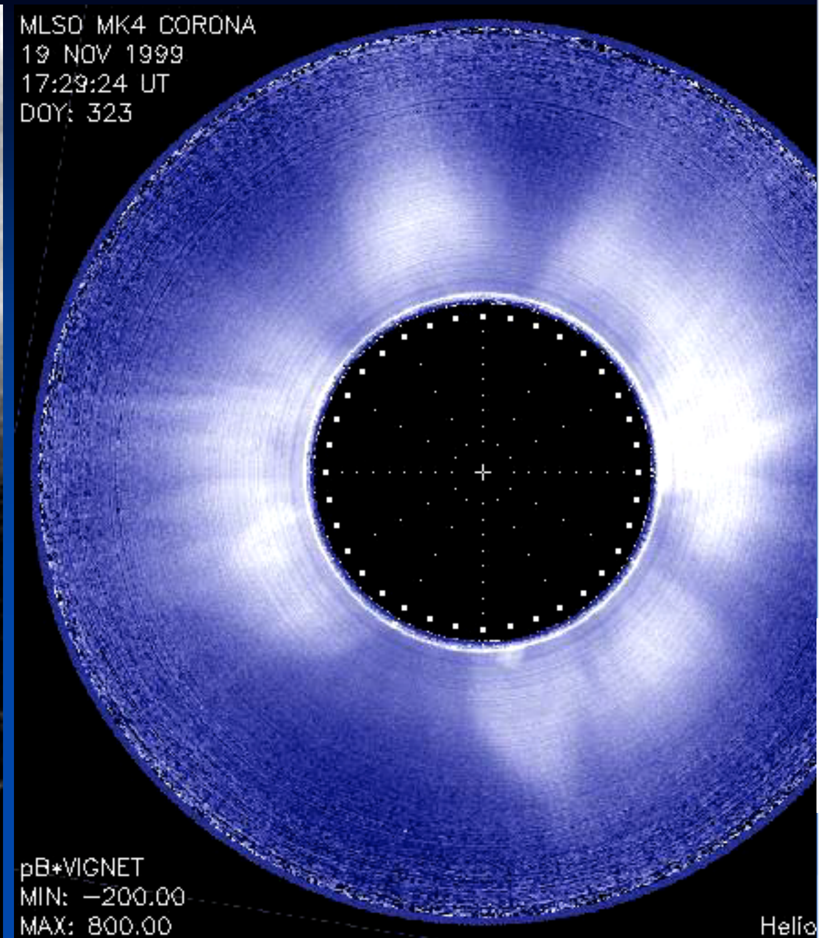
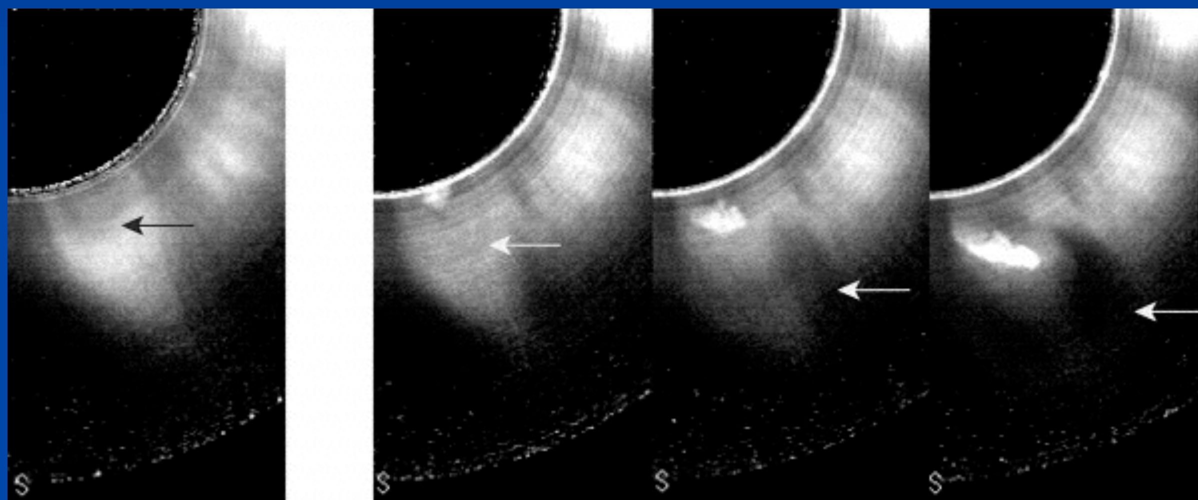
Motivations





- Cavities are known to be correlated with coronal m ejections
- Understanding the physics of cavities is essential to understanding and predicting phenomena such as CMEs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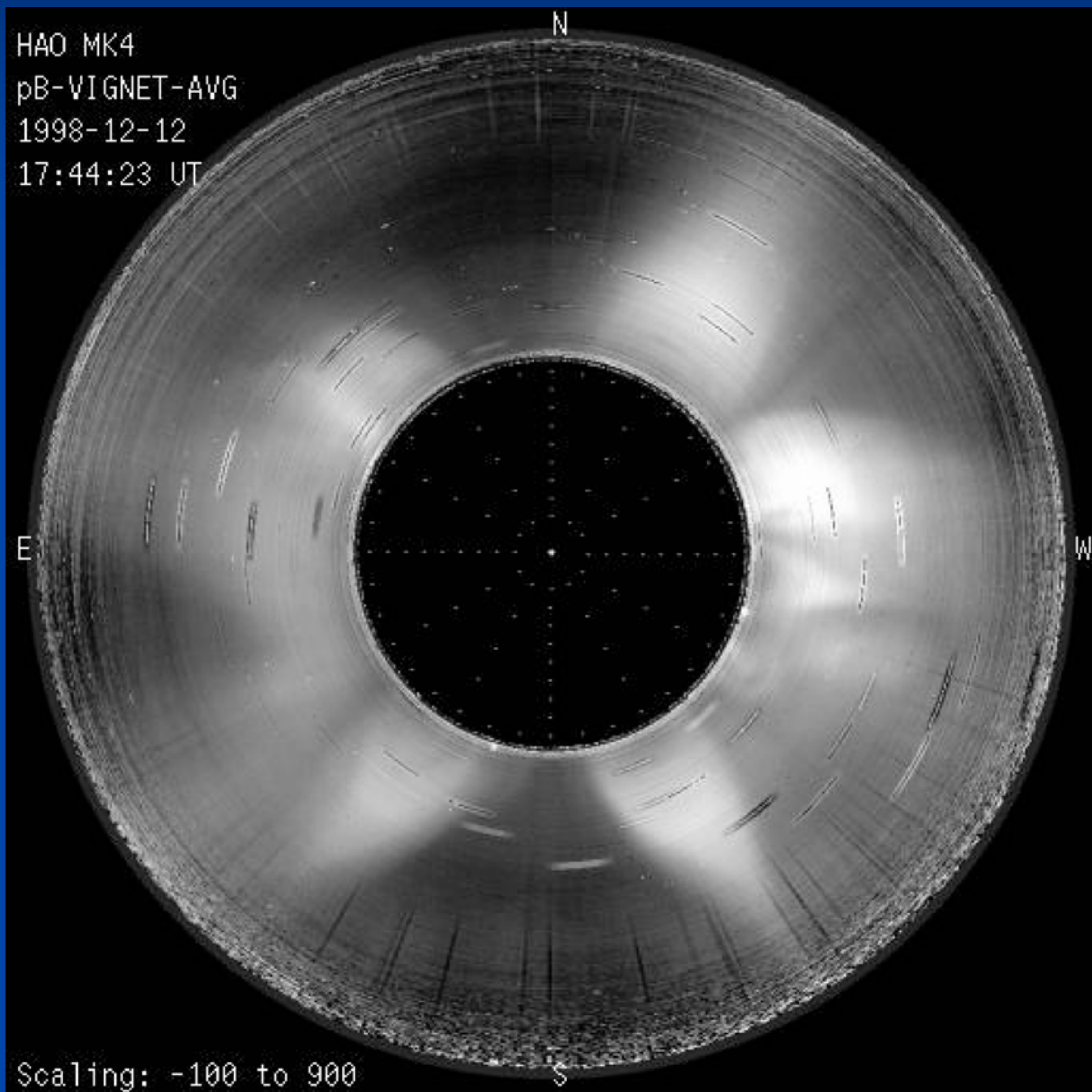
Background

- Cavities are regions with lower density located at the base of coronal helmet streamers
- Cavities are associated with CMEs
- Lower cavity density may imply stored magnetic energy within cavity
- Cavities are often long-term structures

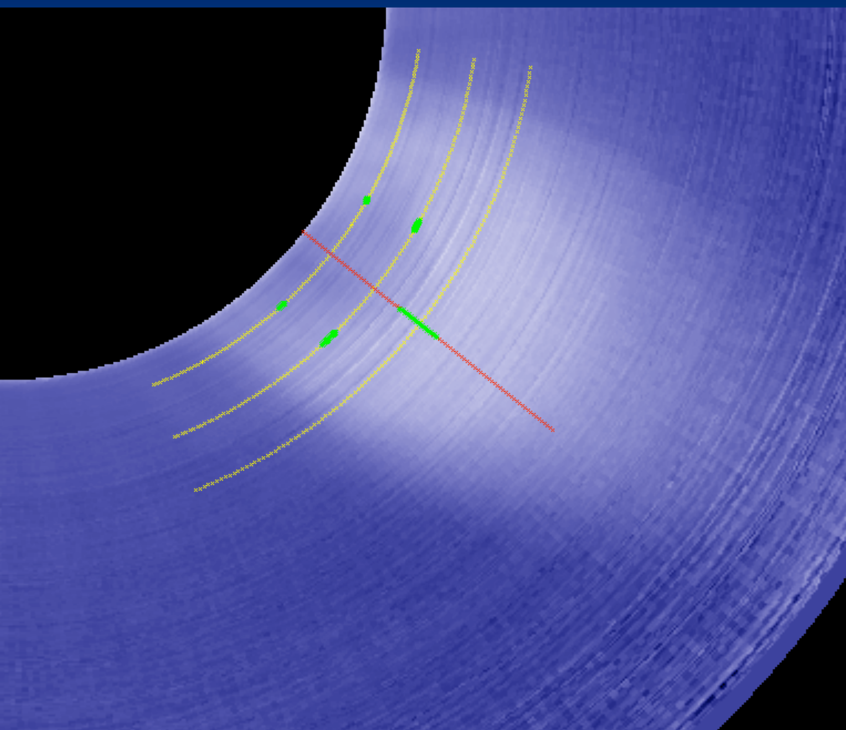
Goals of project

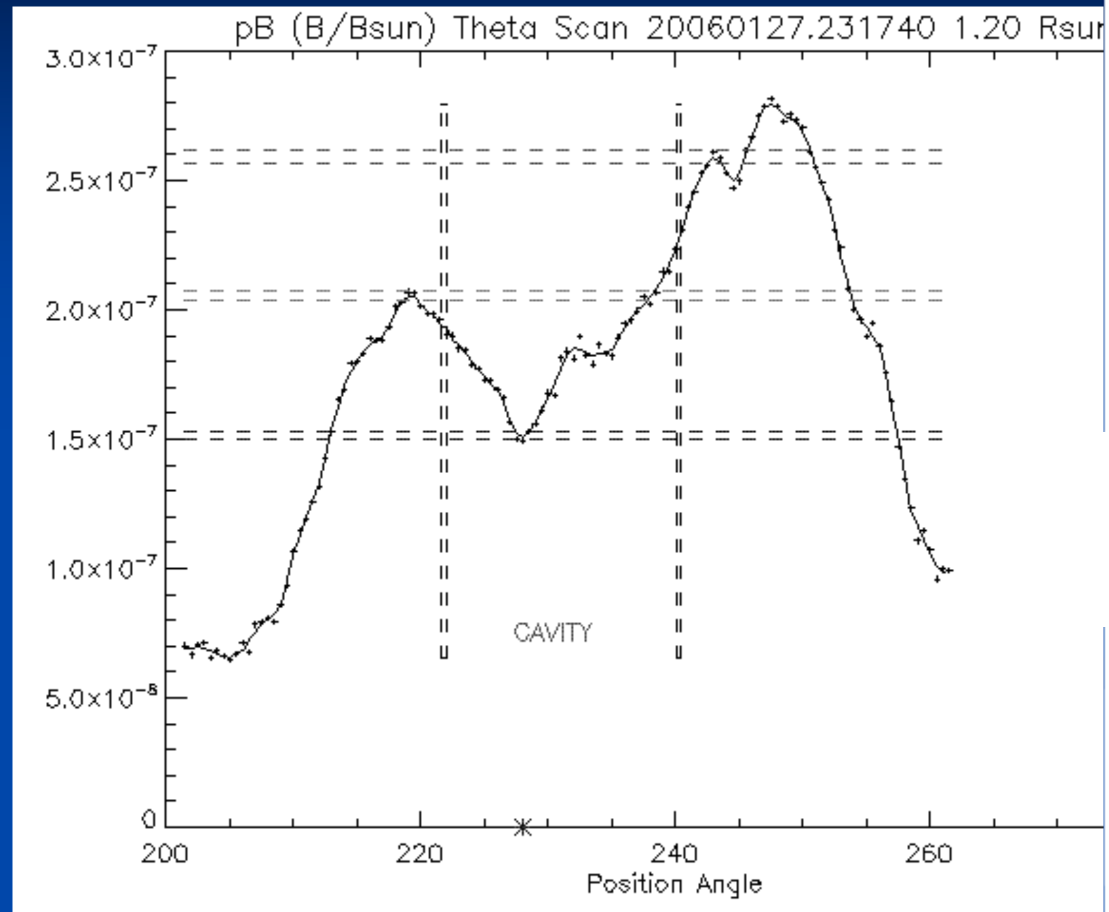
- Create a cavity model that will allow us to observe cavity material
- Find cavities that fit parameters of model so we can claim we are observing only cavity material
- Invert polarized brightness measurements to determine cavity density

Observing a Cavity



- Each pixel brightnes
  an integral over the
  of sight, integral is
  proportional to dens
- Cavity wall, other
  features often get in
  way
- 2D image cannot tel
  3D structure so we
  must observe for
  several days

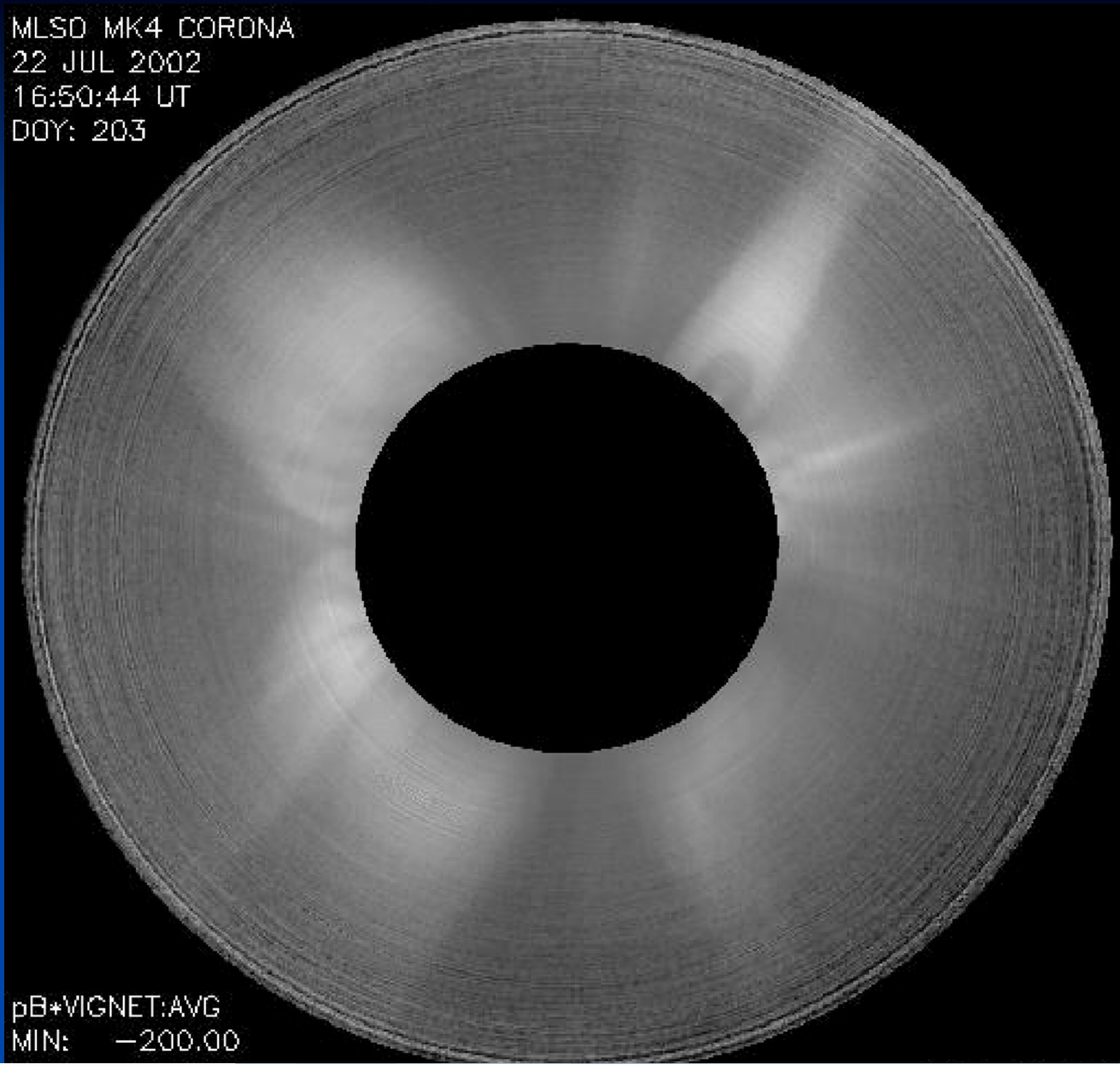


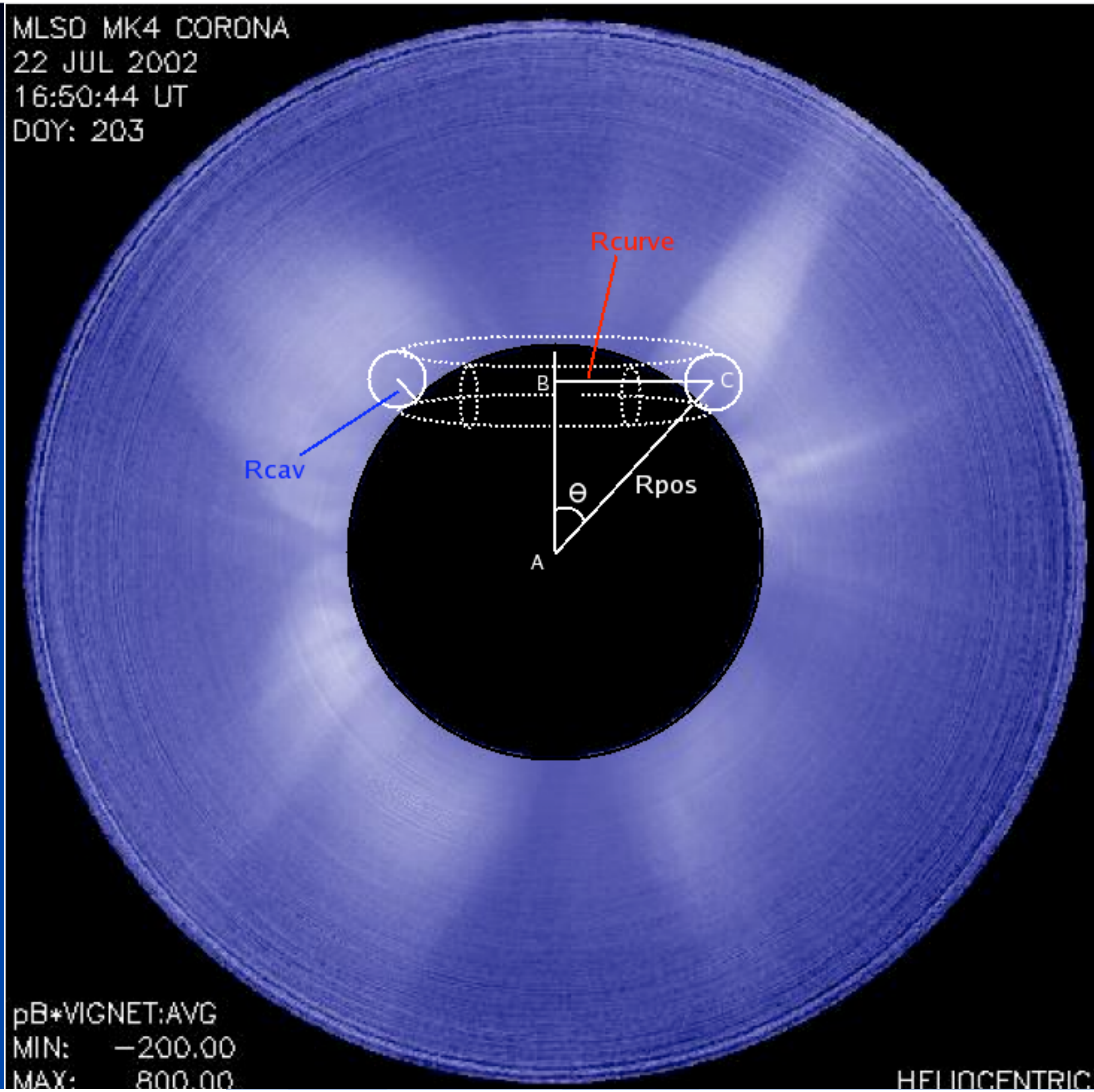


- Polarized brightness measurements as a function of latitude at constant height
- Cavity has lower brightness than rim, higher brightness than coronal holes

Our Model

- Cavity is modeled as an axisymmetric torus encircling Sun at constant latitude.
- The model is not intended to apply to all cavities but will work if cavity has the right properties
- Cavity must maintain constant size and latitude for several days
- Cavity must be large and at low latitudes
- These cavities will allow density analysis


MLSO MK4 CORONA
22 JUL 2002
16:50:44 UT
DOY: 203
pB*VIGNET:AVG
MIN: −200.00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Rcurve
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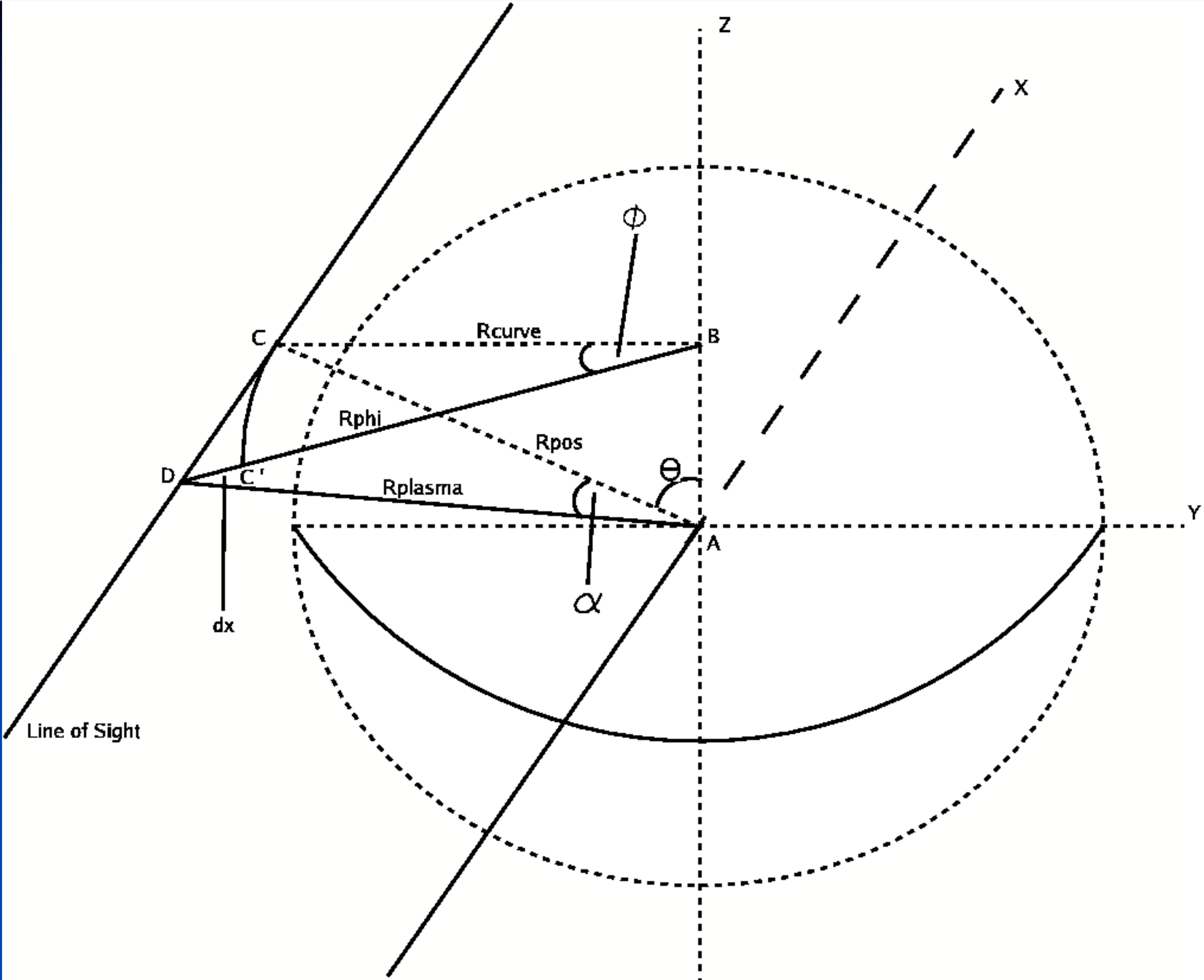

Z
X
ϕ
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Rcurve
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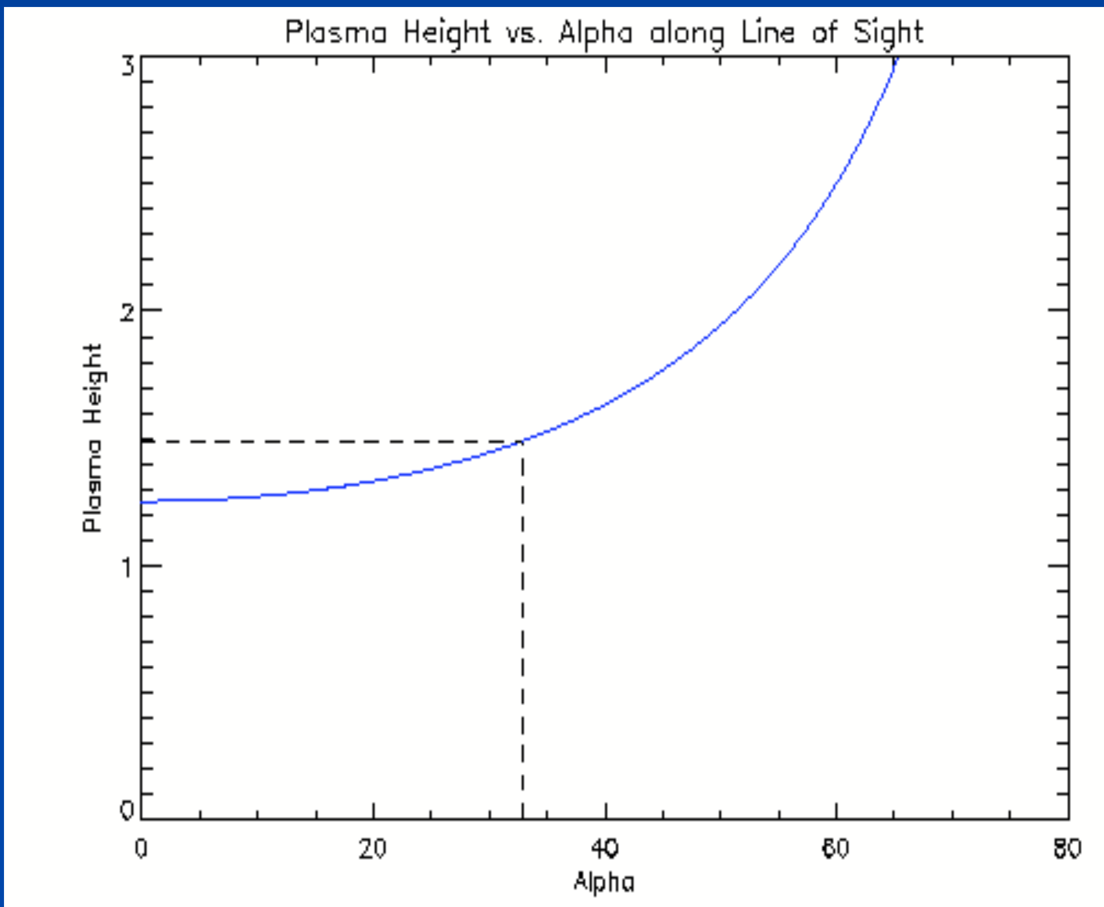
D
C'
Rplasma
Y
A
α
dx
Line of Sight

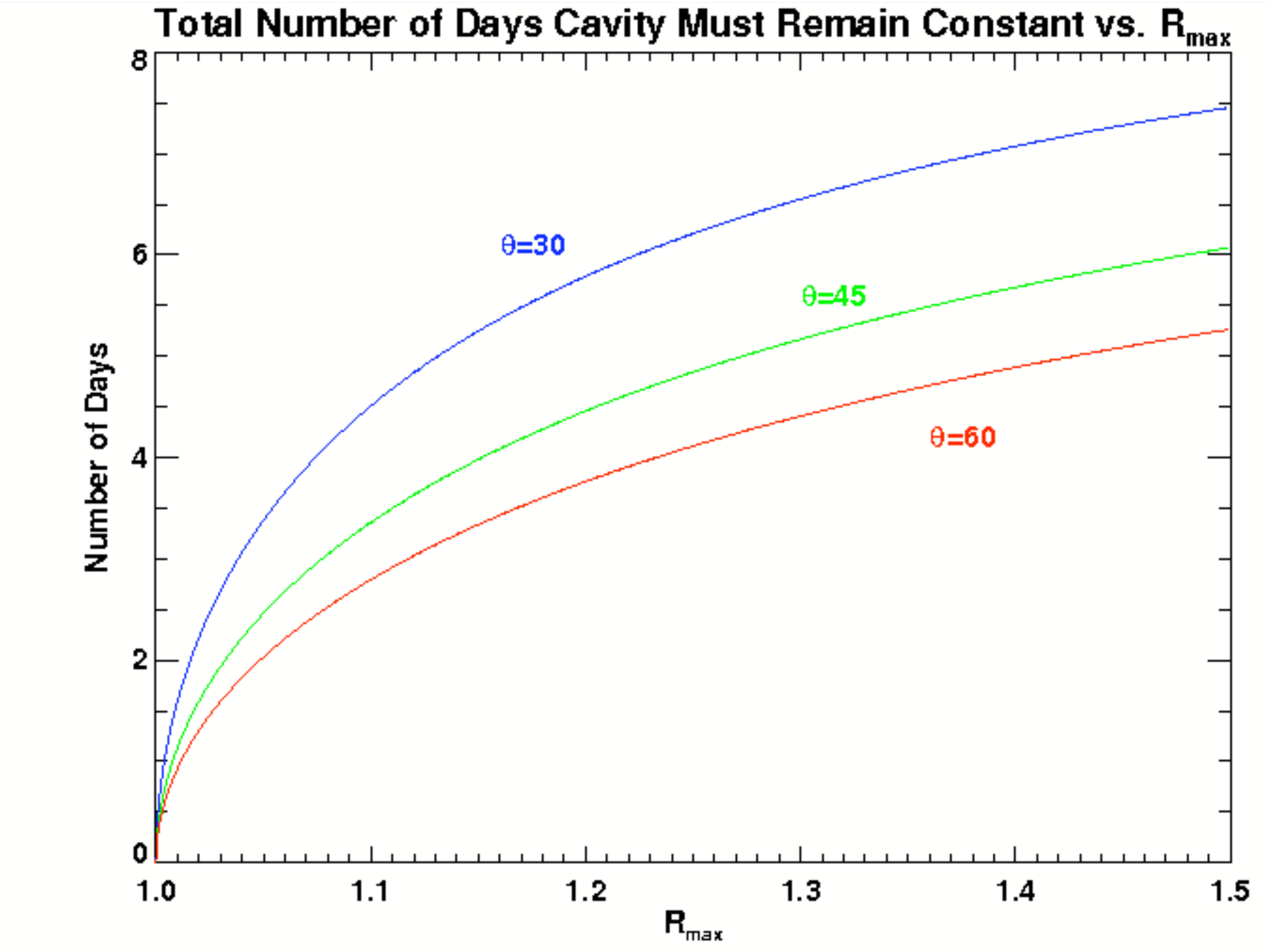
Geometry of Cavity Along Line of Sight



- Material from altituc higher than R_{pos} projects into line of sight as scattering ar increases
- Material from altituc below R_{pos} can never project into line of s

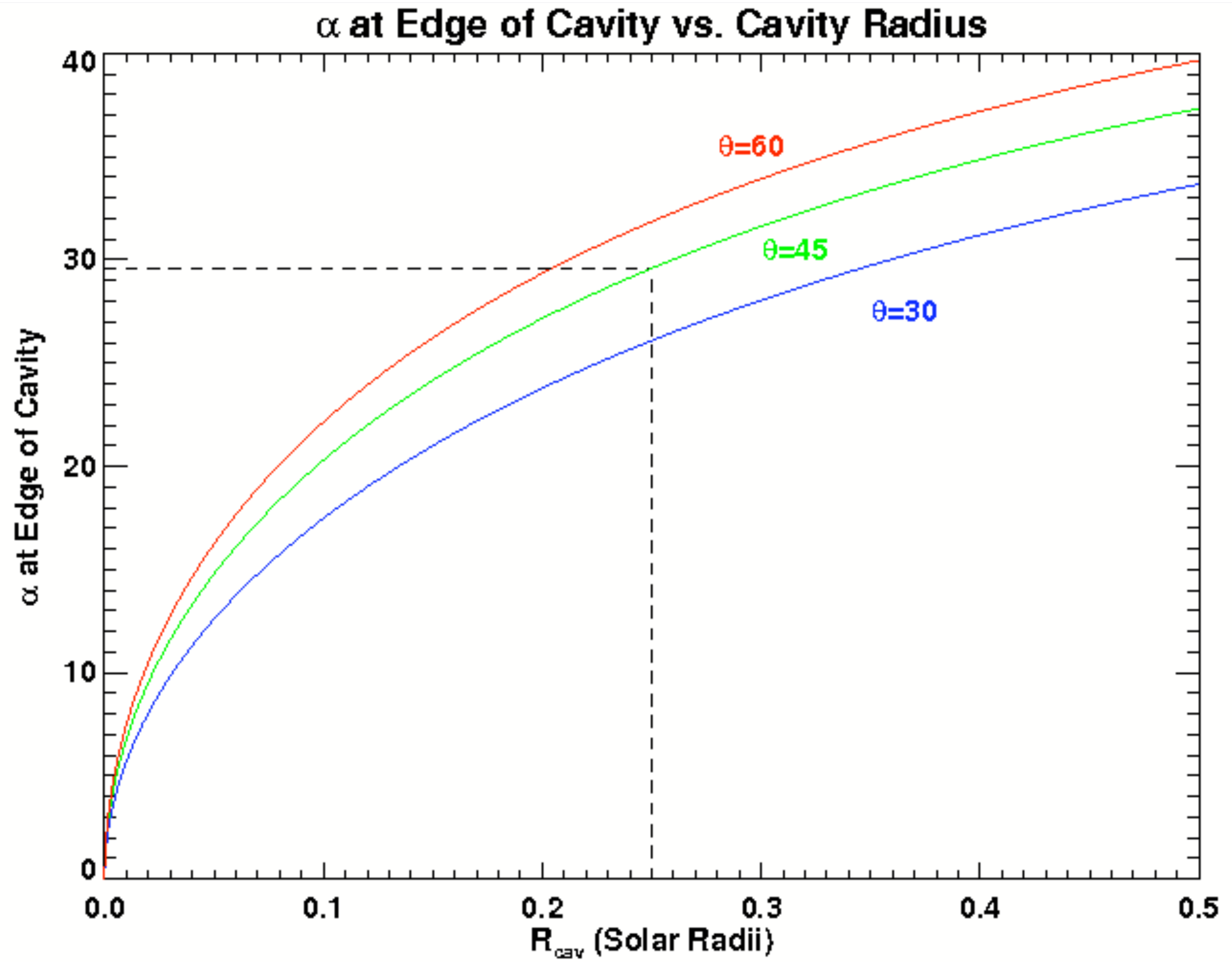
Limitations on Observable Cavities

- Bigger cavities are easier to observe because they extend to larger heights
- Cavities near equator are easier to observe because they curve less
- Cavity must also be visible a couple days before and after observation in order to prove it has larg enough longitudinal extent



- In order to fit ou model, a cavity mu be a large enough of a donut that it i axisymmetric alon our line of sight
- The size of the d slice can be measu by observing how many days a cavity visible

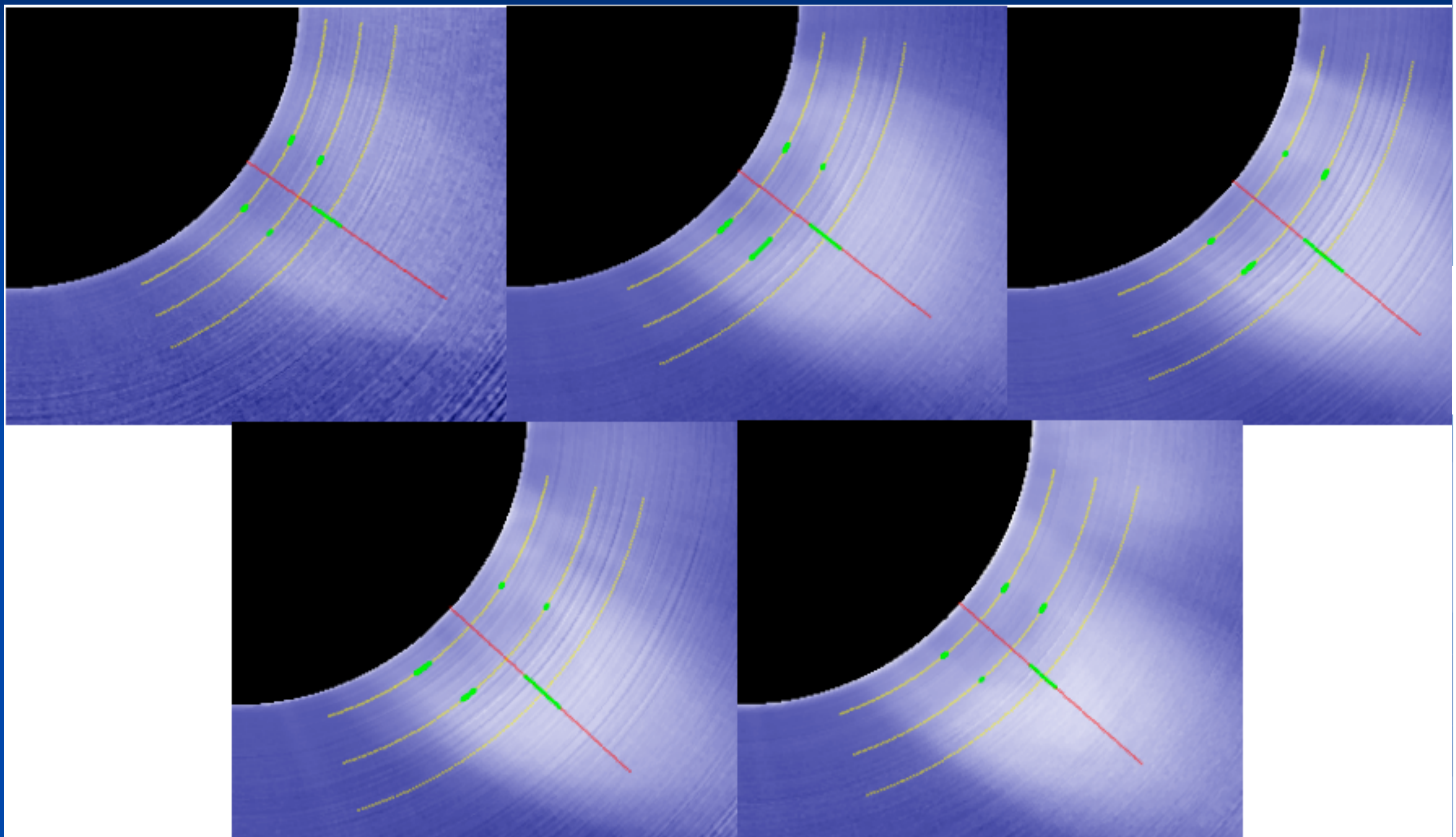
- This plot tells us the total number of days a cavity must be visible that the cavity fits our model and is suitable for observation on the middle day



- Assuming cavity i axisymmetric, a big cavity is best for observation
- Scattering angle a edge of cavity is la for bigger cavities
- This means that n light comes from within the cavity as opposed to outside it

- Scattering angle at edge of cavity also dependent on Rpos
- Lines of sight at low altitudes yield higher scattering angle

Our Cavity



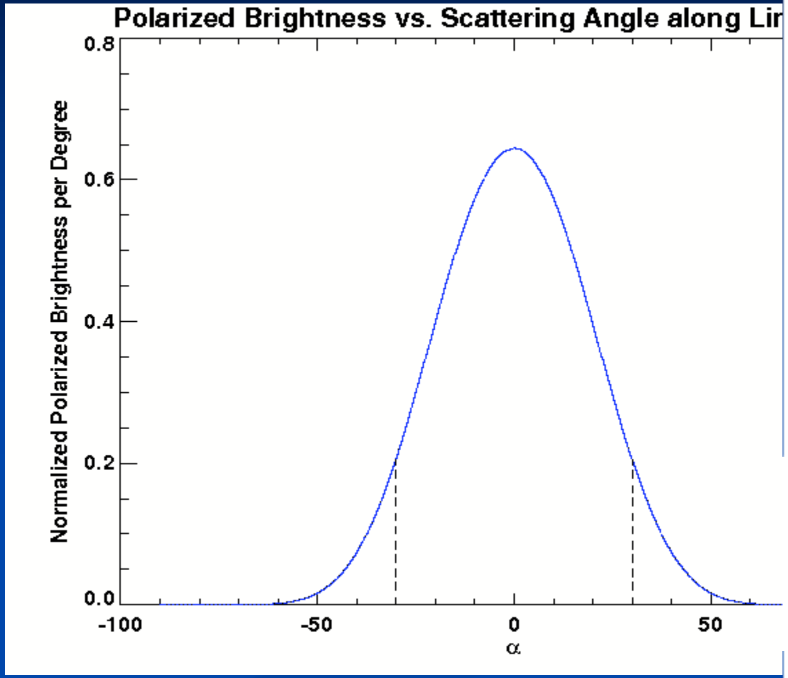
What date works best for measurements?

Date	Days Required	Days Observed
01/25/06	$2.50^{+.11}_{-.13}$	0 before, 5 after
01/27/06	$2.66^{+.13}_{-.13}$	2 before, 3 after
01/28/06	$2.71^{+.14}_{-.17}$	3 before, 2 after
01/29/06	$2.80^{+.14}_{-.17}$	4 before, 1 after
01/30/06	$2.70^{+.10}_{-.13}$	5 before, 0 after

Our cavity is almost axisymmetric on the 27^{th} and 28th

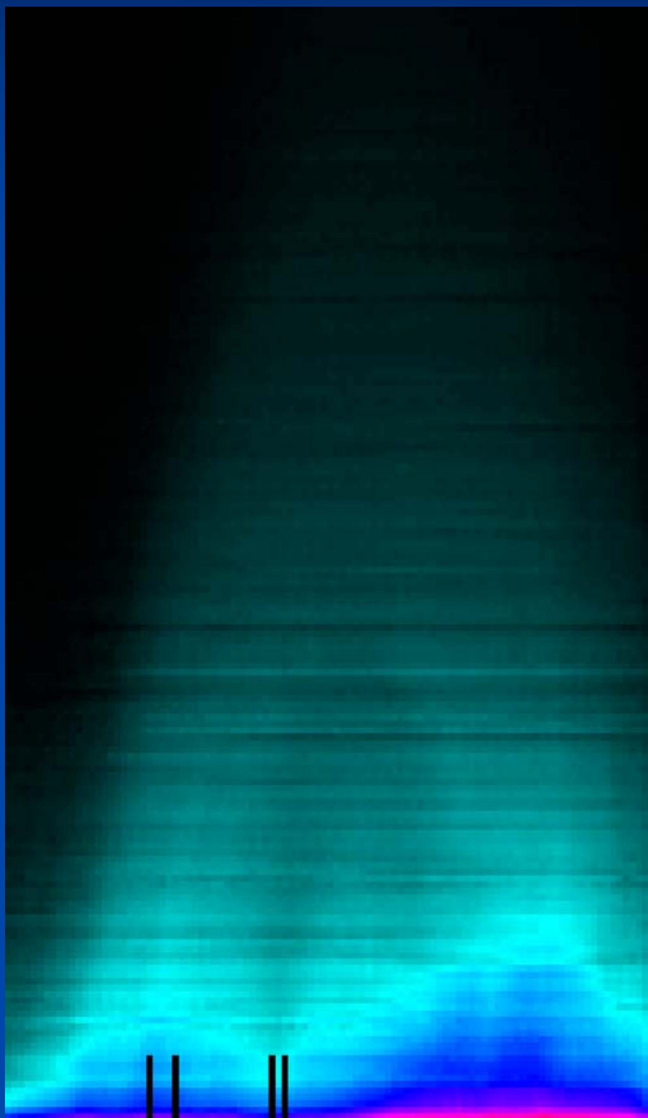
Cavity Properties

Date	R_{cav}	θ	α_{max}
01/25/06	$.230 \pm .030$	$124.80 \pm .74$	$30.32^{+1.48}_{-1.65}$
01/27/06	$.260 \pm .035$	$128.44 \pm .63$	$31.17^{+1.53}_{-1.71}$
01/28/06	$.270 \pm .045$	$129.64 \pm .67$	$31.40^{+1.85}_{-3.14}$
01/29/06	$.285 \pm .045$	$132.40 \pm .89$	$31.54^{+1.81}_{-3.07}$
01/30/06	$.260 \pm .030$	$131.36 \pm .54$	$30.69^{+1.32}_{-1.45}$



- Cavity is big and fairly close to the equator so α_{max} is large
- Plot at right (Hundhausen 1993) shows polarized brightness as function of α for Rpos=1.25
- Over 88% of light comes from within our cavity if we observe it Rpos=1.25

Calculating Cavity Density



Step 1:

- Select regions at which to ma radial polarized brightness measurements
- Heights below 1.18 contaminated by substructure
- Heights above 1.4 measure v little cavity
- Beware of active regions!

Problem

- Van de Hulst inversion requires cylindrical symmetry of density fall off, i.e. the radial fall off must be identical at all scattering angles
- Jump in density from cavity to cavity rim breaks this symmetry

Uncertainties

- Inversion requires value:

$$pB_{cav}\Big|_{-90}^{90} = 2pB_{cav}\Big|_{\alpha_{max}}^{90} + 2pB_{cav}\Big|_{0}^{\alpha_{max}}$$

- The measured value is:

$$pB_{meas} = pB_{cav} + pB_{non} = 2pB_{cav}\Big|_{0}^{\alpha_{max}} + 2pB_{non}\Big|_{\alpha_{max}}^{90}$$

- The value given to our program is:

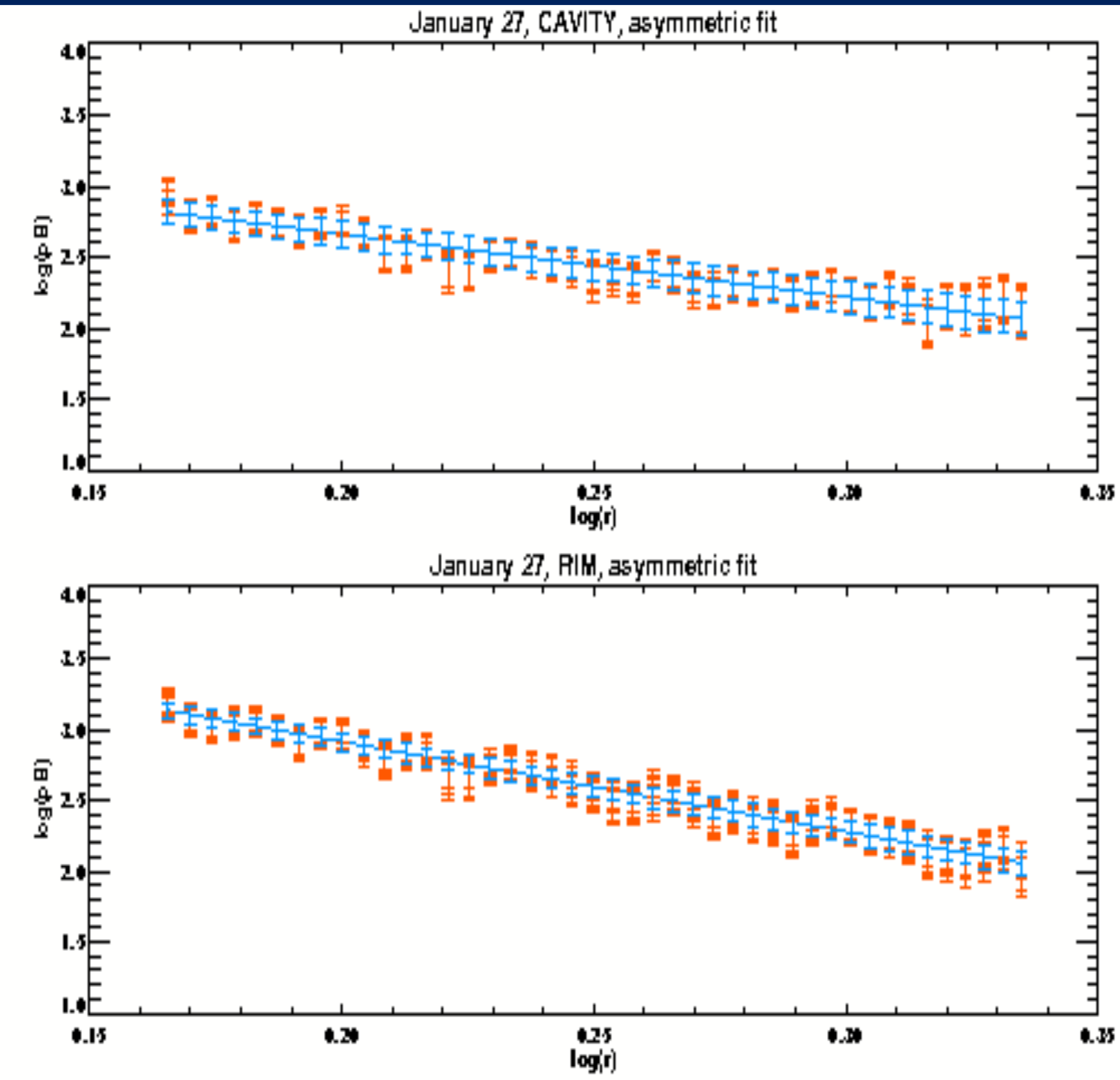
$$pB_{cav}\Big|_{-90}^{90} = pB_{meas} + \left(2pB_{cav}\Big|_{\alpha_{max}}^{90} - 2pB_{non}\Big|_{\alpha_{max}}^{90}\right)$$

where the term in parentheses is the uncertainty in measurement

Another Problem

- Cavity is not quite axisymmetric
- Using number of days before and after observation, we calculate values of α_{max} in front of and behind cavity at which line of sight exits cavity
- Uncertainties utilize smallest values of α_{max} to ensure account for largest possible error

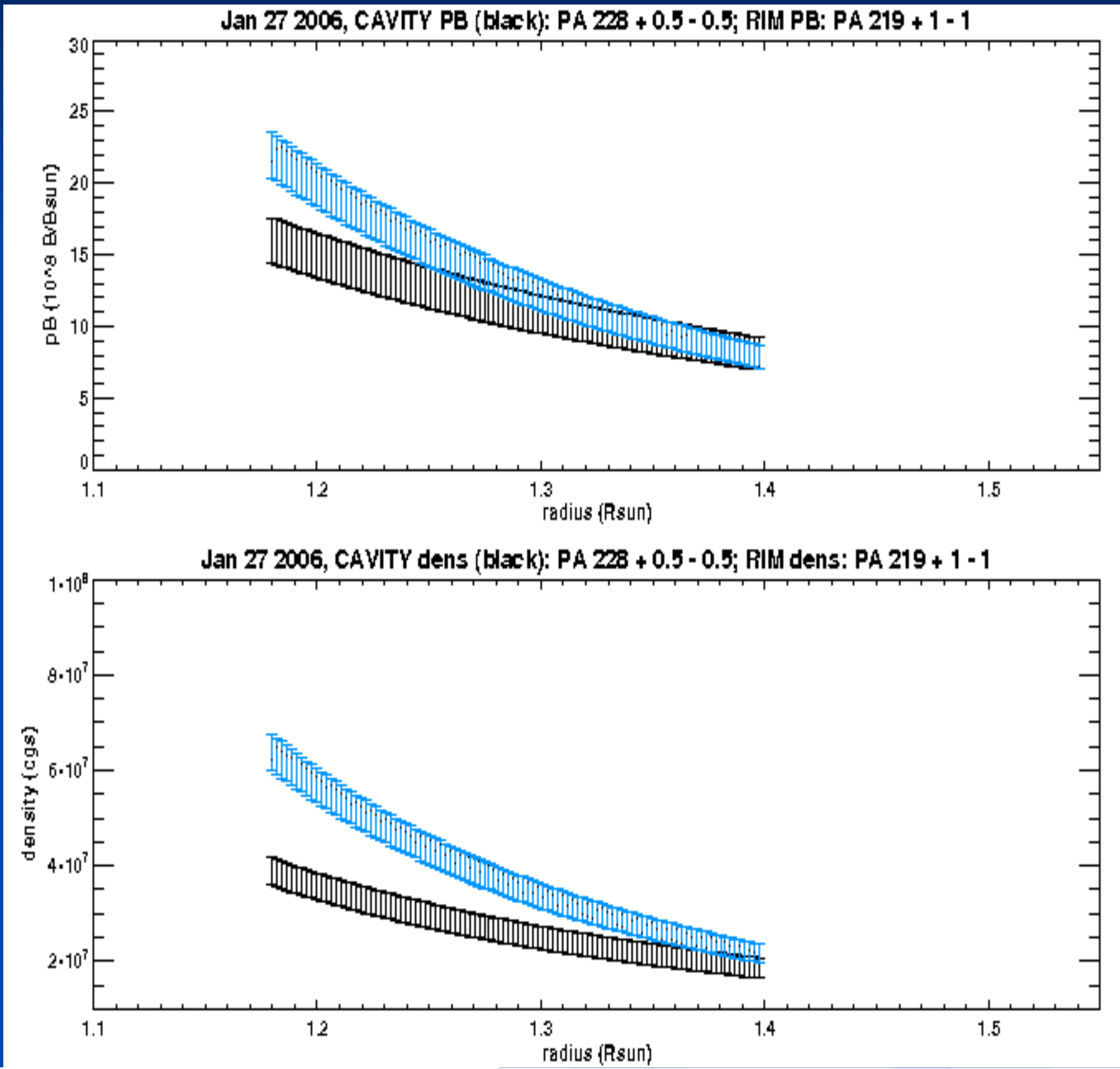
Fitting a curve to pB measurements



Step 2:

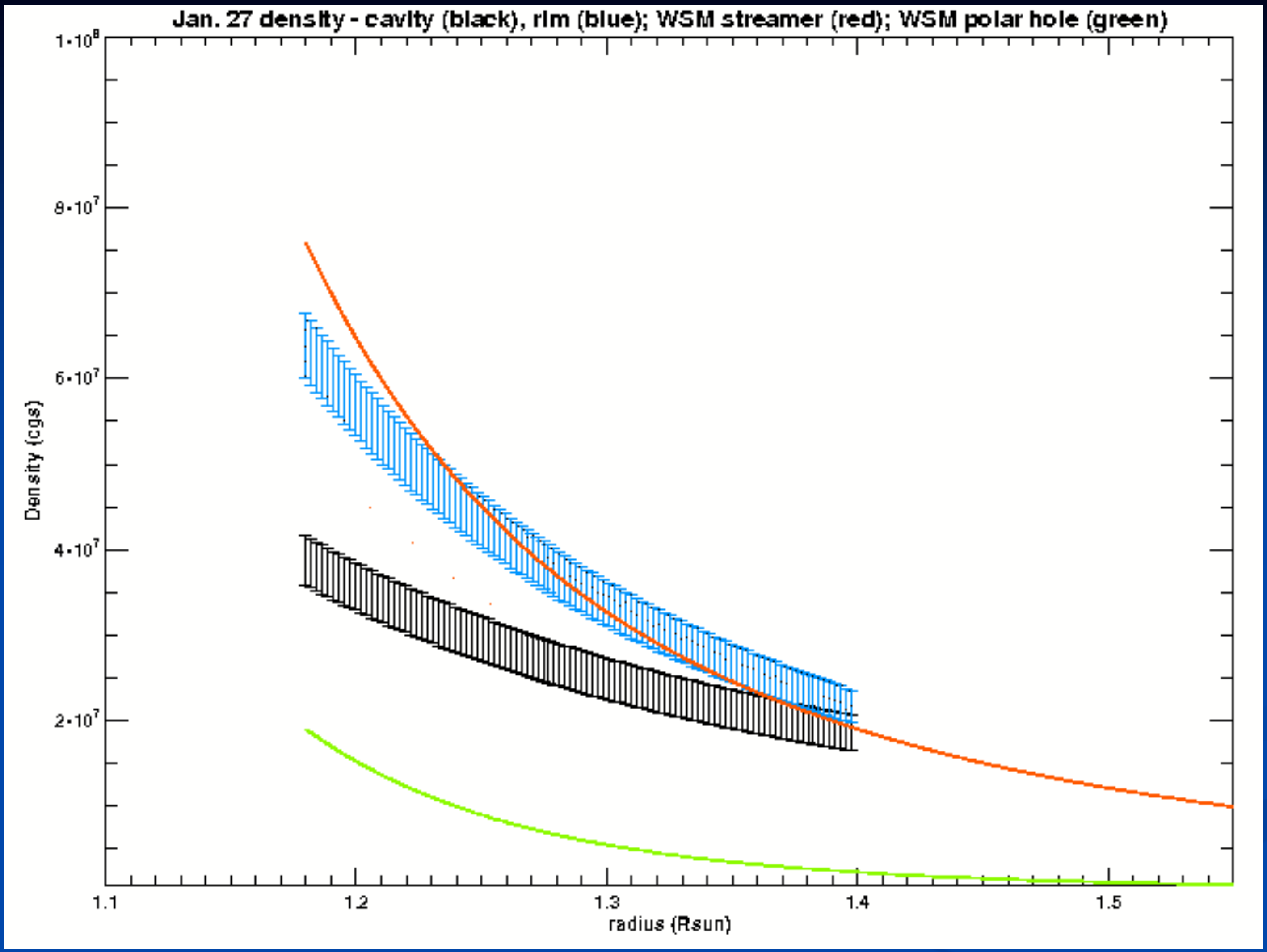
- Create log(pB) log(r) plot
- Log-log plot h linear profile
- Our program determines parameters of li of best fit

Calculating Cavity Density



Step 3:

Using calculat
fit parameters
perform Van
Hulst inversio
and calculate
density profile



- Cavity has about 60-100% the density of the cavity rim
- Cavity has about 2-5 times the density of a coronal hole
- Cavity rim has very similar density to a bright helmet streamer

Implications

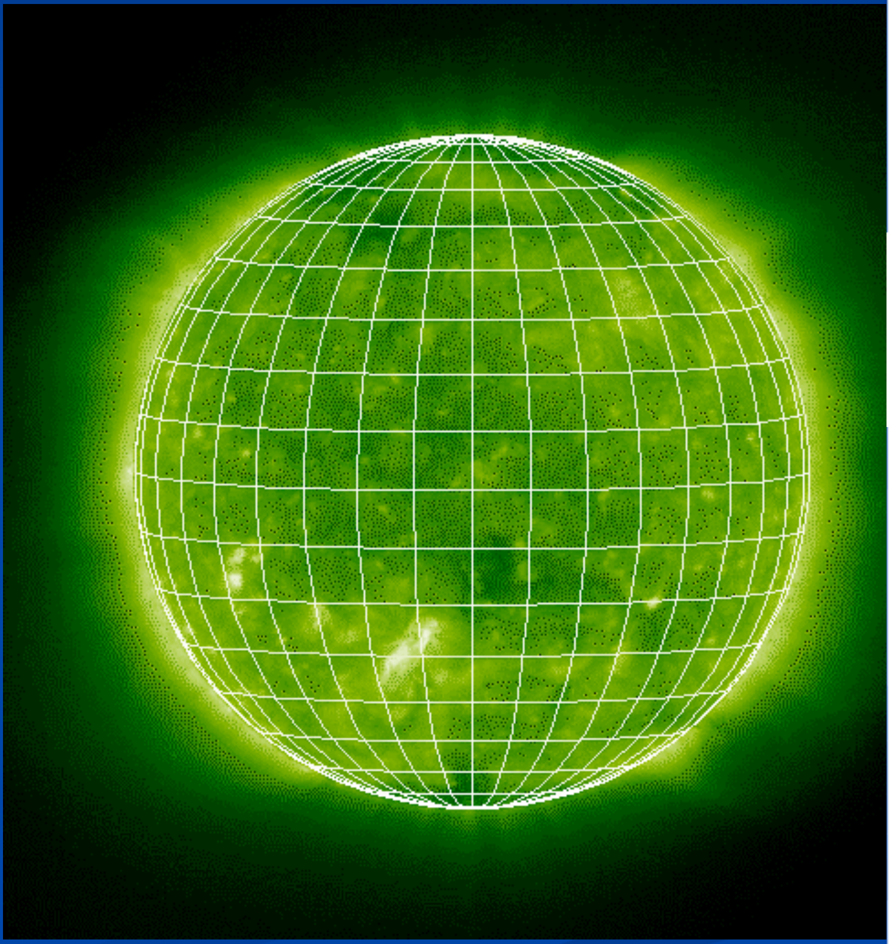
- Cavity has lower density than rim and slower density fall off
- To ensure pressure continuity, cavity must have higher temperature or higher magnetic pressure
- Our results are consistent with models in which cavity is created by twisted magnetic flux rope
- Twisted magnetic flux rope would create a higher magnetic pressure and flatter density fall off within cavity

Conclusions

- People have said that cavities are unobservable because the helmet streamer gets in the way and because cavities are empty
- We have demonstrated cases in which contribution from the helmet streamer are negligible and have proven that cavities are far from empty
- Our results reveal a density profile that is consisten with the magnetic flux rope model for cavities

Future Work

- Apply this technique to more cavities
- Apply geometry of the model to cavities imaged in emission lines
- Submit article for publishing
- Use emission line data to determine temperature profiles of cavities



References

- Gibson, S.E., Fludra, A., Bagenal, F., Biesecker, D., De Zanna G., & Bromage, B. 1999, J. Geophys. Res., 104, 9691
- Gibson, S.E., Foster, D., Burkepile, J., de Toma, G., & Stanger, A. 2006, ApJ, 641, 590
- Guhathakurta, M., Fludra, A., Gibson, S. E., Biesecker, D., & Fisher, R. 1999, J. Geophys. Res., 104, 9801
- Hundhausen, A. J. 1993, J. Geophys. Res., 98, 13177
- Van de Hulst, H.C. 1950, Buttetin of the Astronomical Institutes of the Netherlands, 11, 135