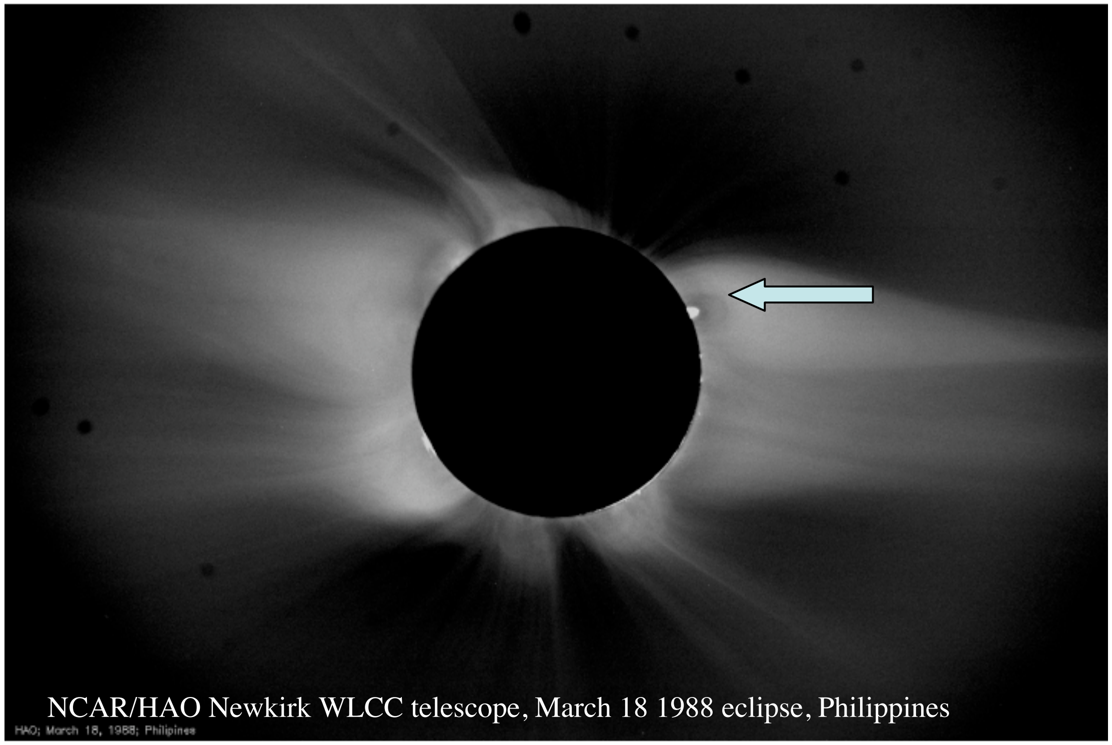
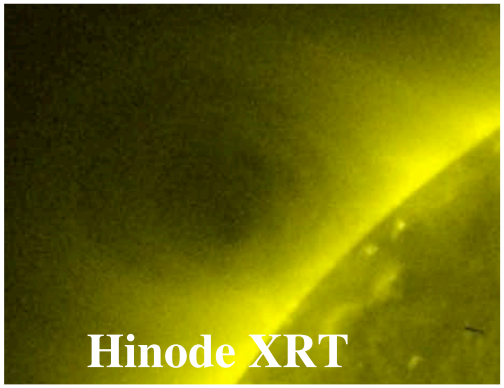
Quantifying the physical properties of coronal cavities



Sarah Gibson

Hinode XRT and EIS: David Brooks, Kathy Reeves, Alphonse Sterling, Durgesh Tripathi, and David Williams
HAO: Jim Fuller, Don Schmit, Giuliana de Toma and Yuhong Fan

Talk outline



Prominence cavities are fundamental parts of prominences:

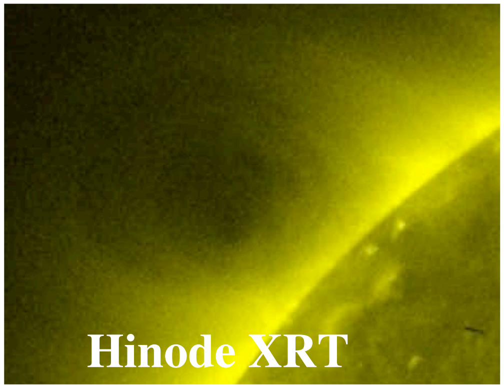
- give clues to magnetic structure of pre-CME equilibrium
- can be directly linked to CMEs and magnetic clouds

But are **not nearly as well observed as prominences**. We don't even know if cavities are hotter or cooler than surrounding helmets. Why?

- projection effects can complicate interpretation of observations
- diagnostic studies require targeted observations, and sufficient plasma

Recent work modeling the **3D geometry** of polar crown filament cavities, combined with new **Hinode and STEREO** observations, has made a detailed **analysis of cavity physical properties possible.**

Talk outline



Background and motivation

3D model geometry

Calculating cavity density from white light

Implications for cavity temperature and magnetic field

Cavities in emission

Conclusions

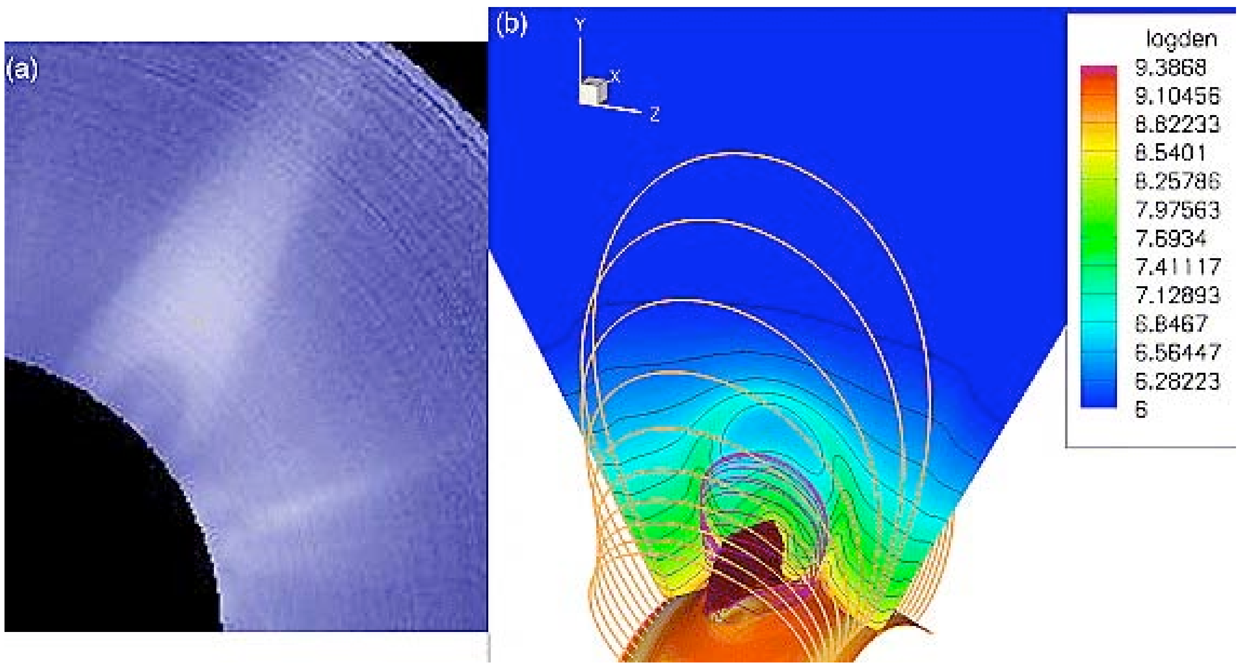
Background: Cavity/flux-rope as MHD equilibrium state

Coronal magnetic helicity very nearly conserved as a global quantity *Berger and Field (1984)*

Magnetically dominated plasma relaxes to min. energy conserving helicity *Taylor (1974; 1986)*

Free energy stored in still-twisted magnetic fields is plausible CME driver *Low (1999)*

Flux ropes **“fundamental building blocks of magnetism in the solar atmosphere”** *Rust (2003)*

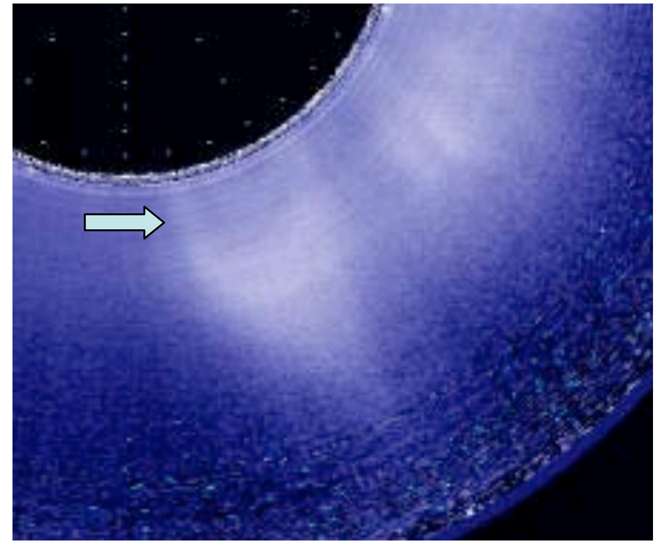


Gibson and Fan (2006)

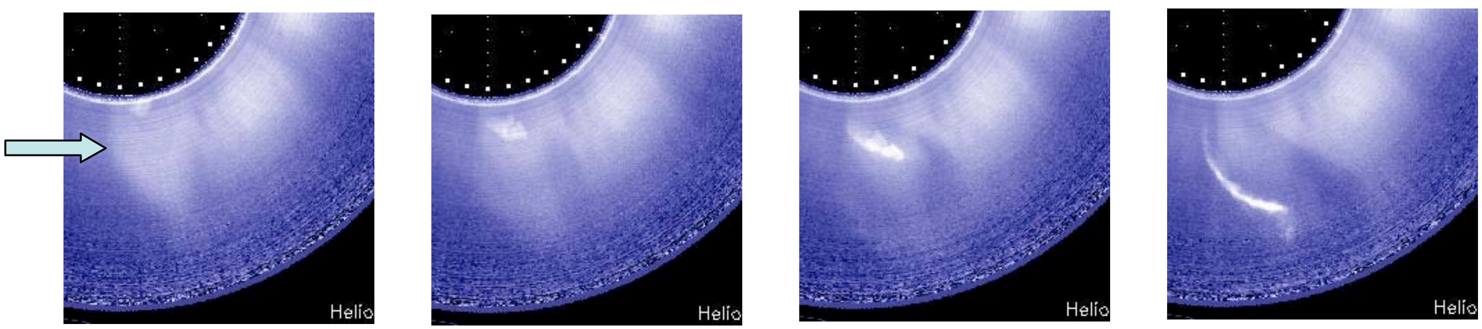
Model of CME as pre-existing flux rope--> **observable: quiescent filament cavity**

Background: Cavity --> CME

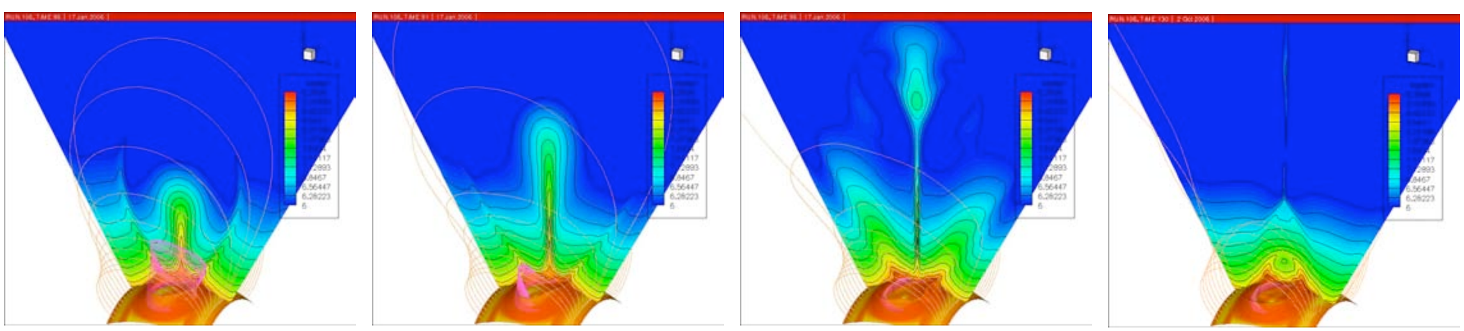
- Cavites are known to be CME precursors
- Consistent with loss of equilibrium of pre-existing magnetic flux rope



Quiescent cavity: November 18, 1999



CME eruption of cavity: November 19, 1999 *Gibson et al. (2005)*

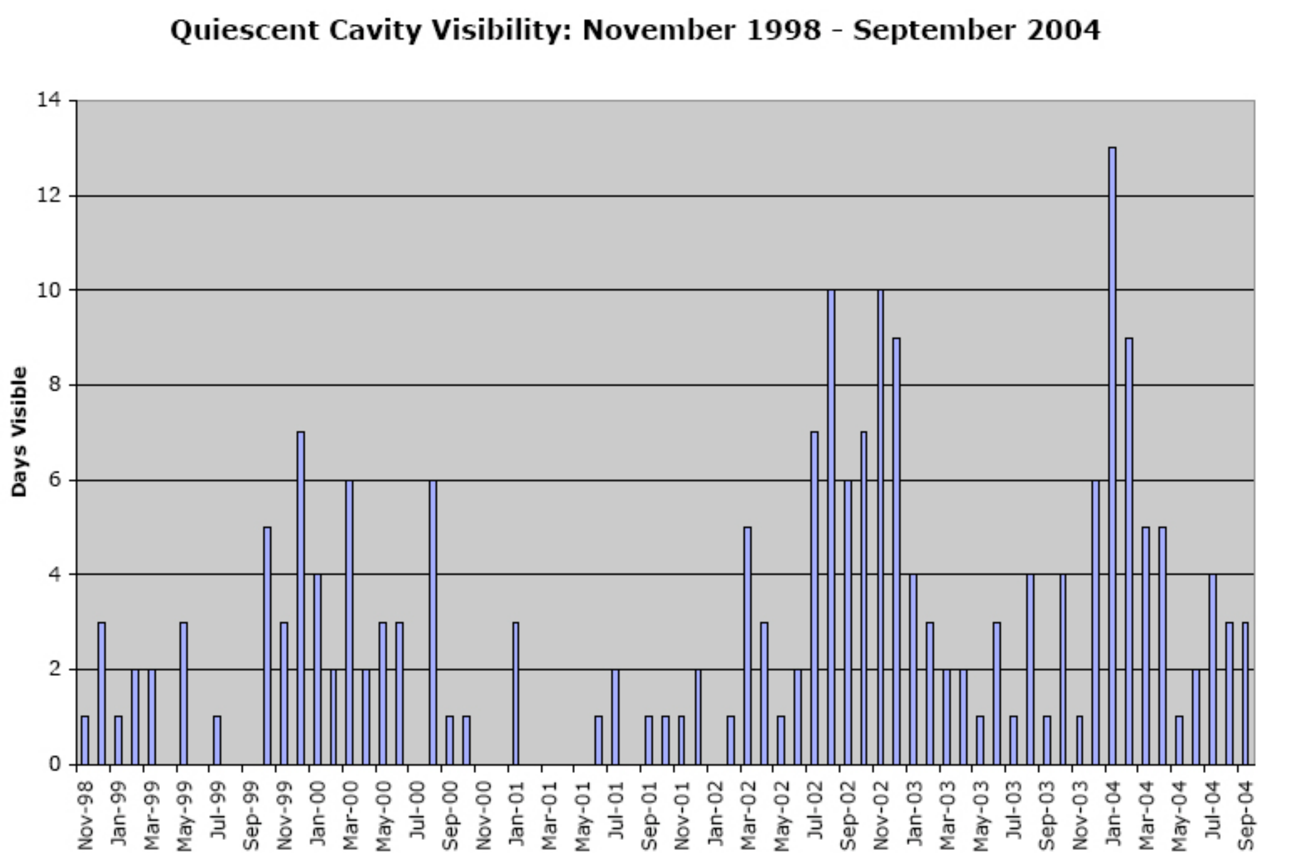


CME eruption of cavity: flux rope model *Gibson and Fan (2006)*

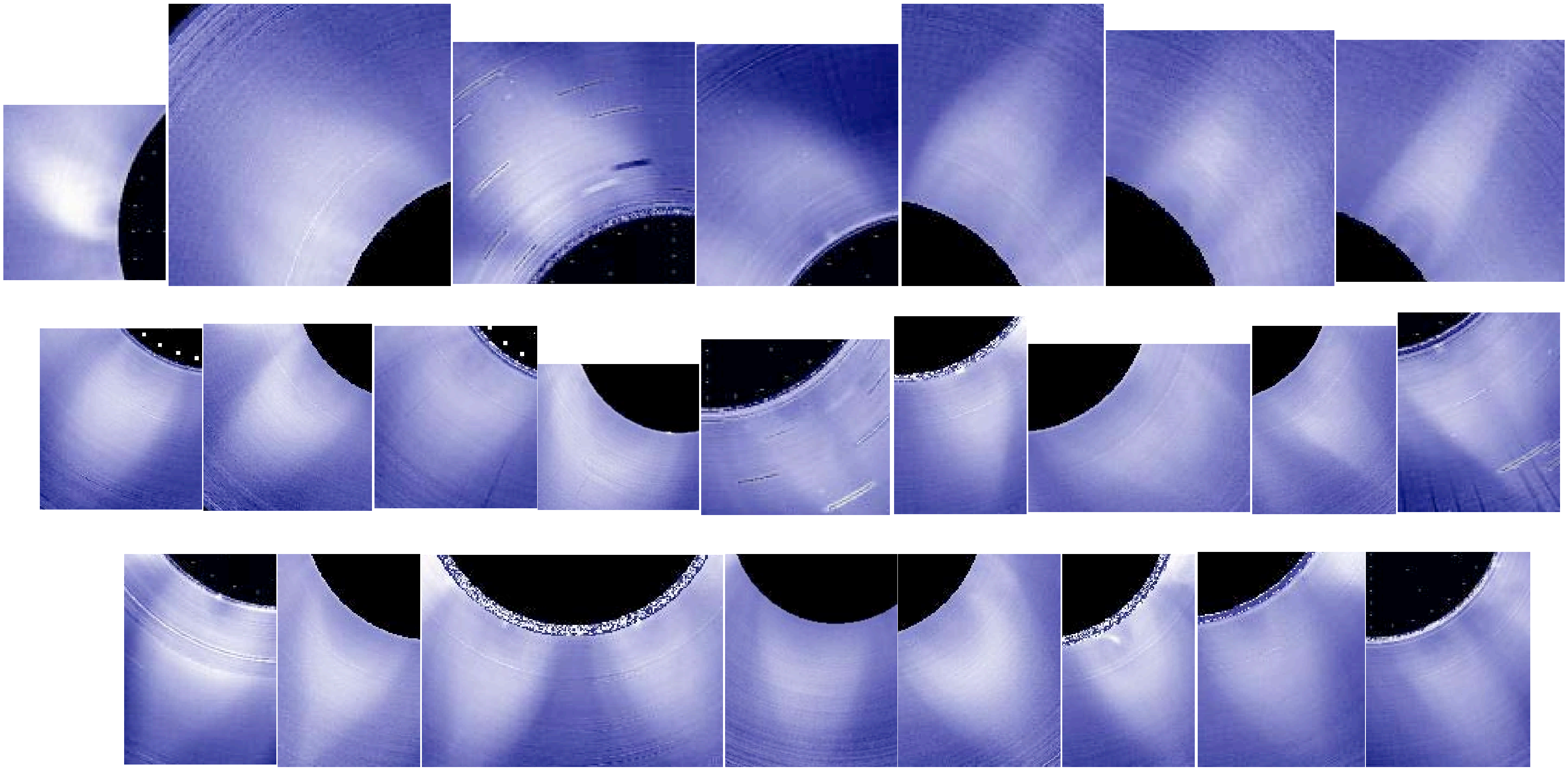
Background: Cavities are ubiquitous

All days November 1999 -- September 2004 where HAO/MLSO Mark IV coronagraph showed clear cavities: **206 days with clear cavities**

- **Solar cycle effect** -- more cavities visible during descending phase
- **Correlated with polar crown filament visibility**
- **Lower limit** on days with cavities -- many more identified if cavity systems examined in detail



Background: Cavities are ubiquitous



Background: Cavities come in many sizes

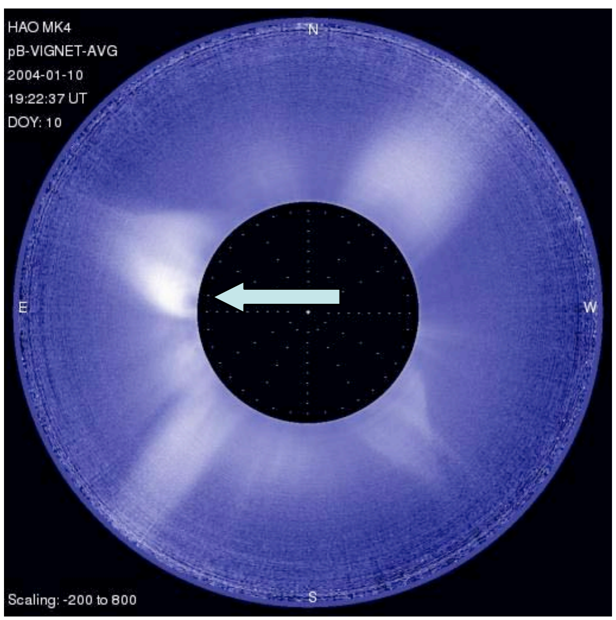
(all values **Minimum/Mean/Maximum**, **12 system best only**, **full dataset of 88**)

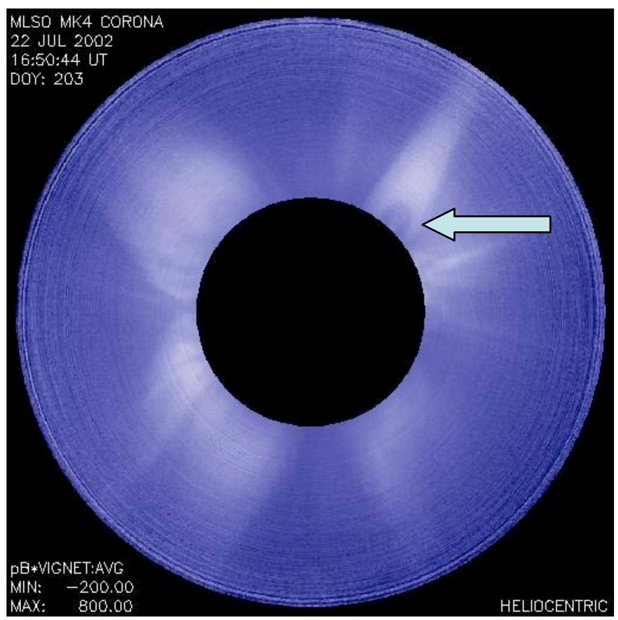
1. Cavity distance from equator: **5/56/77** **5/56/90** **degrees**

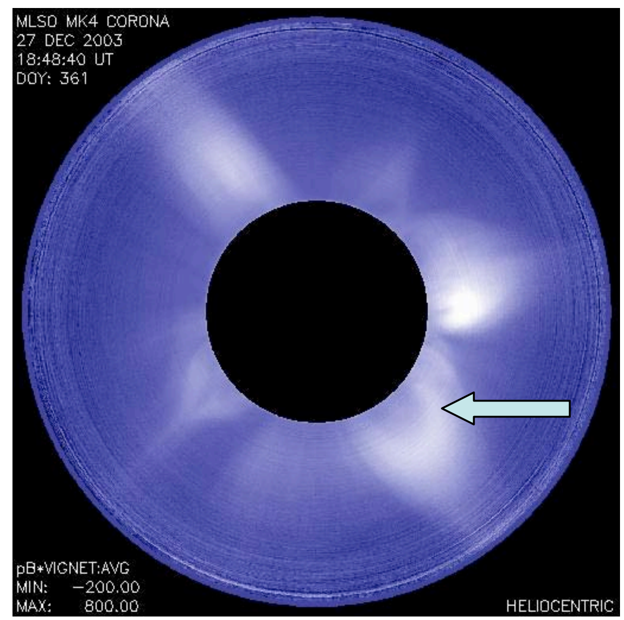
2. Cavity width: **6/18/36** **4/19/40** **degrees**

3. Cavity height: **1.25/1.47/1.60** **1.24/1.46/1.64** **Rsun**

Gibson et al. (2005)

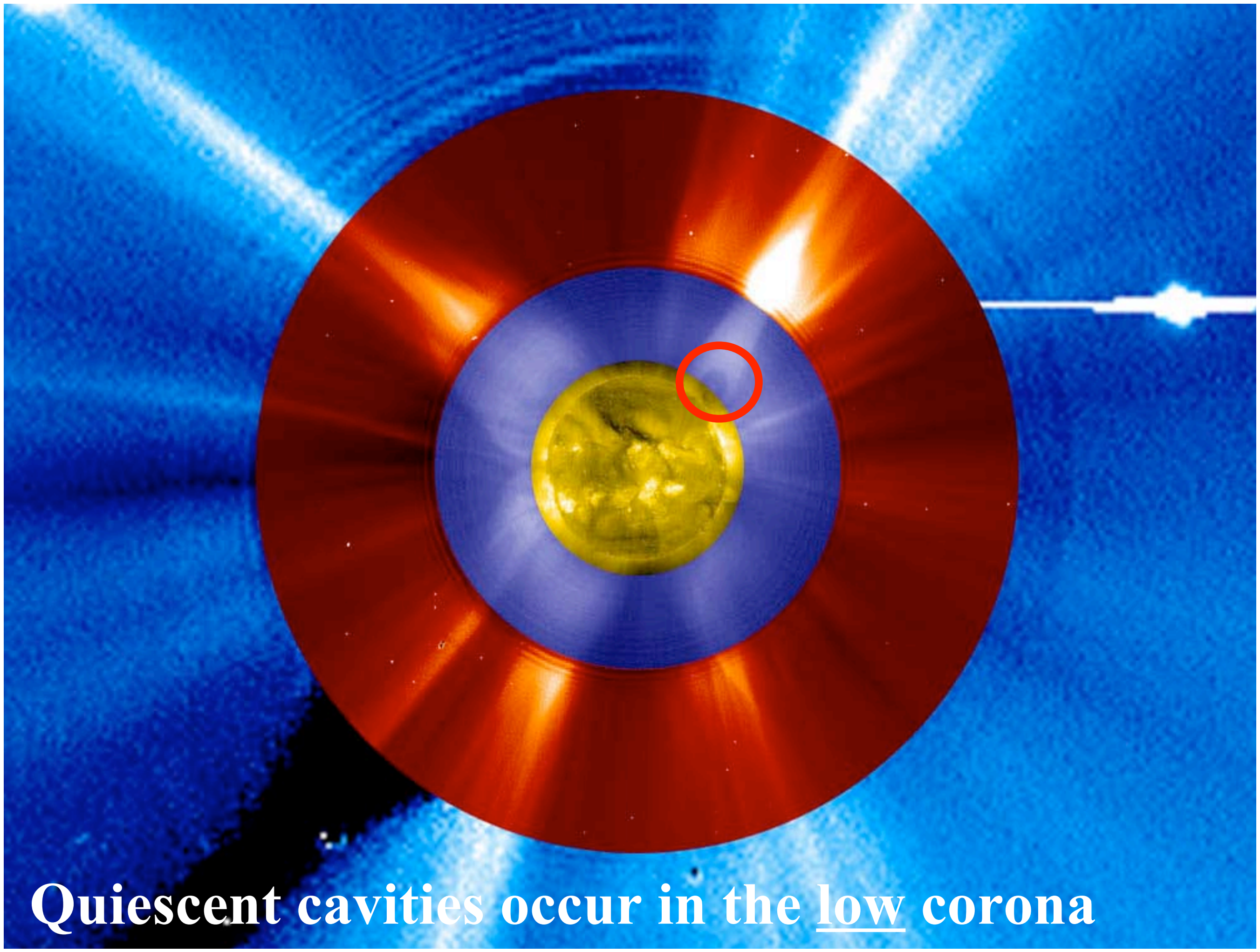






Background: Cavities come in many sizes

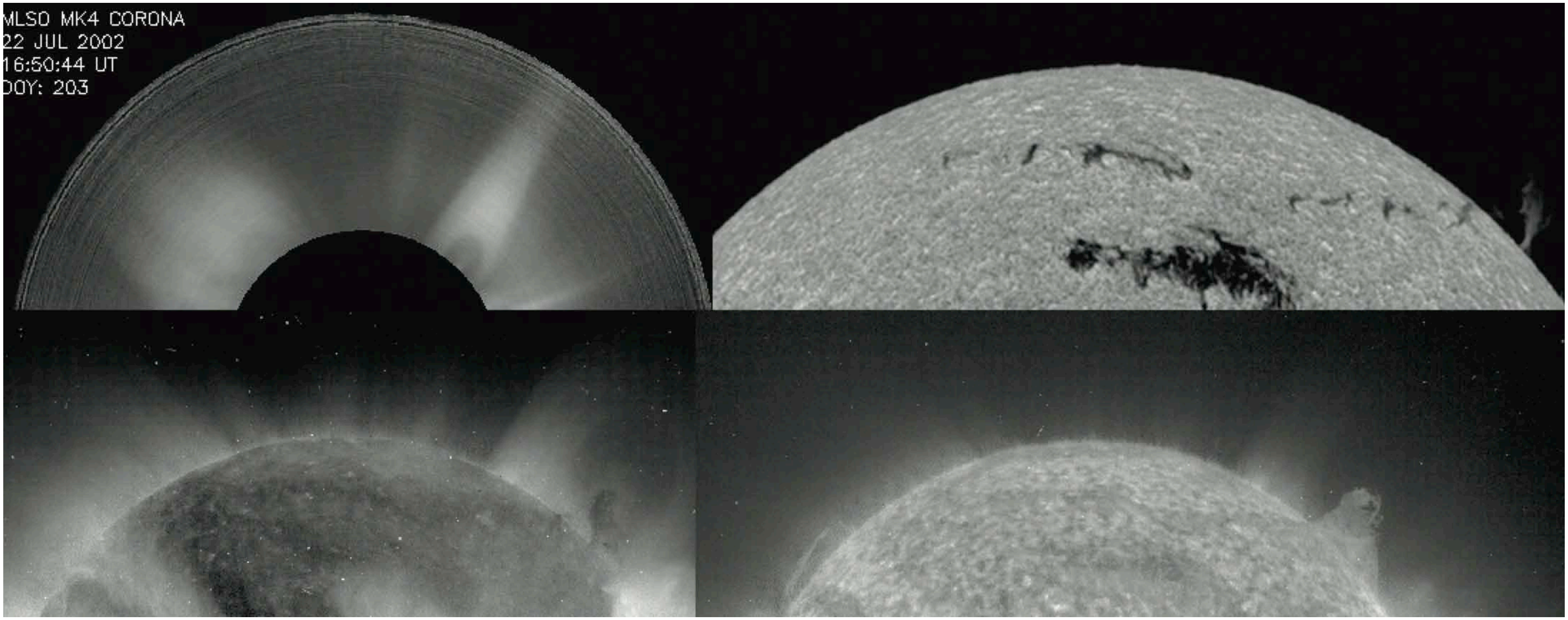
…But all are relatively low-lying!



Innermost to outermost: EIT 284, Mark IV, Lasco C2, Lasco C3

Background: Cavities as filament channels

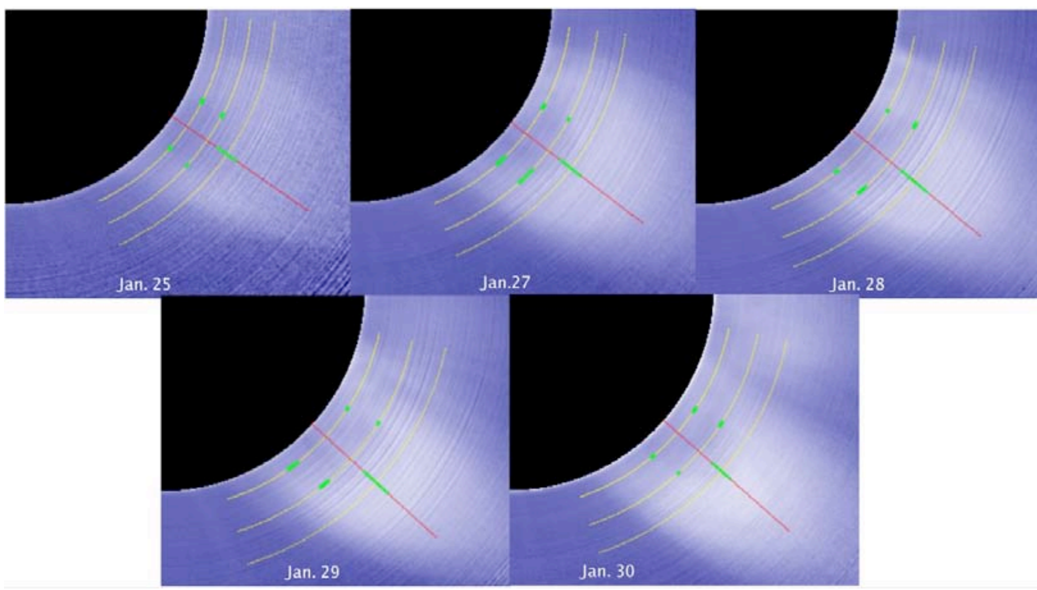
Prominence cavity = filament channel viewed at limb:

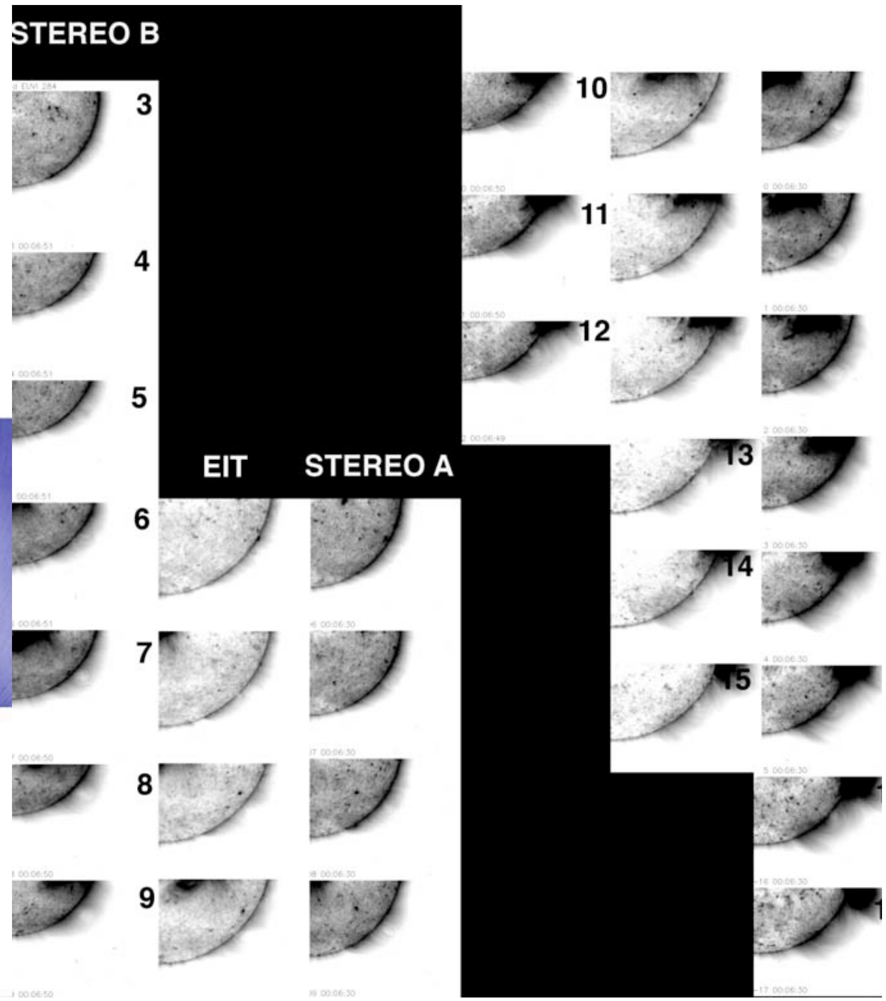


3D model geometry *(Fuller et al, 2008)*

Problem: quantitative interpretation of cavities is complicated by the potential for projection of non-cavity plasma along the line of sight

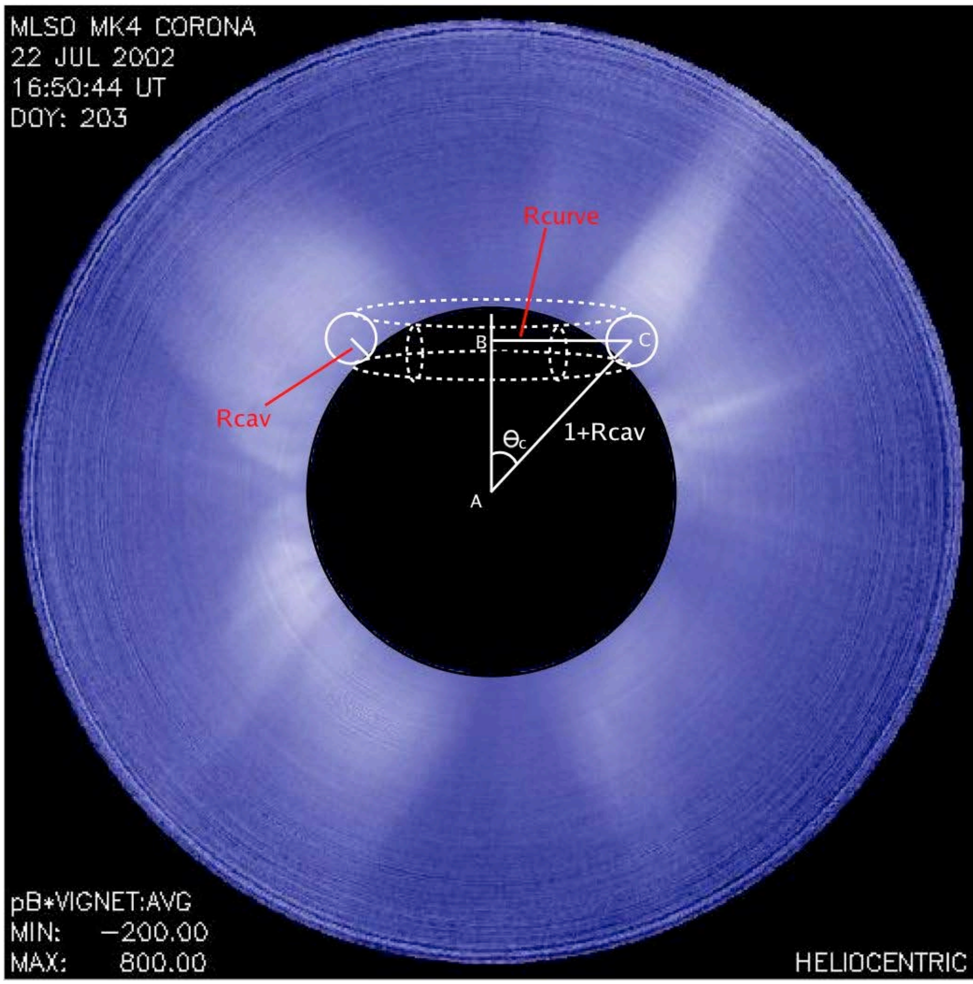
Our solution: use geometric arguments and observations over several days (and/or from multiple viewpoints) to establish cases where non-cavity contributions are minimal, and include them as model uncertainties

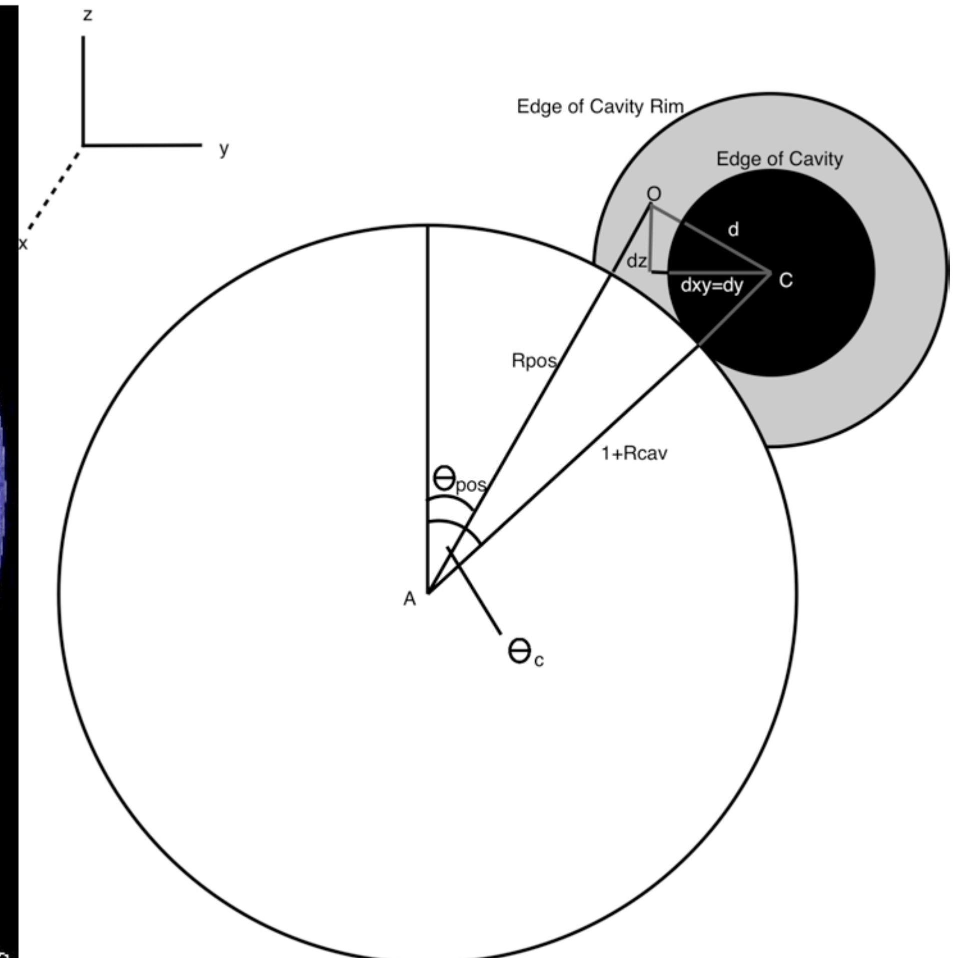




3D model geometry: cavity as axisymmetric "tunnel"

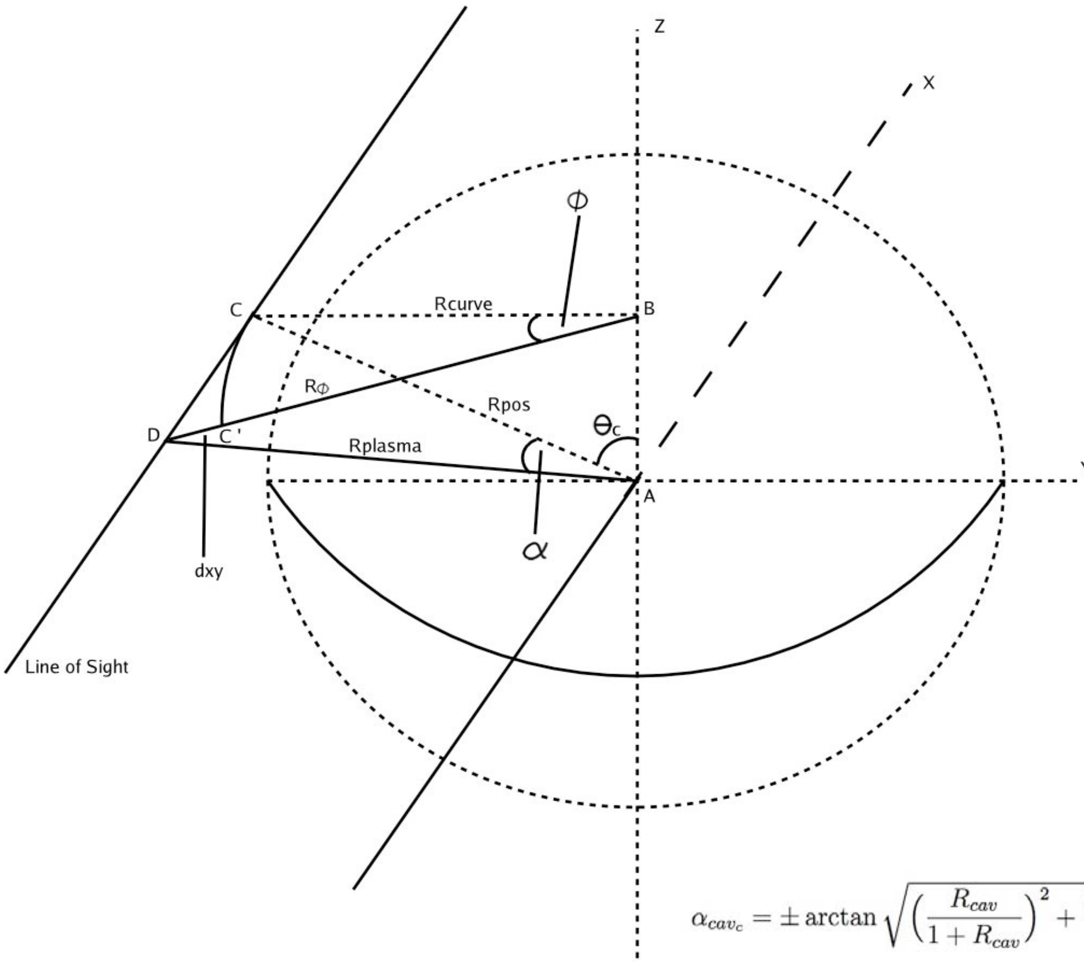
- Matches observations of polar crown filaments (PCFs)
- Cavity rim as denser surrounding tunnel



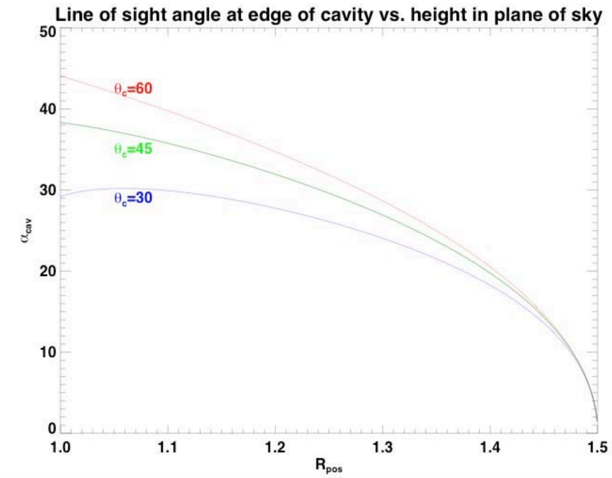


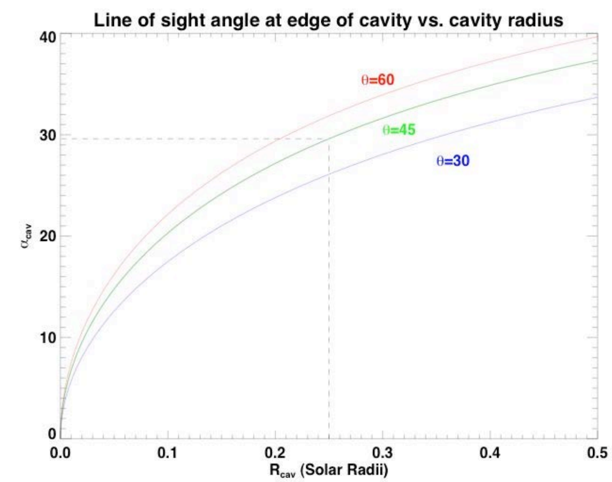
3D model geometry: best cavities for avoiding <u>rim</u> projection

- Better for lower plane-of-sky heights
- Better for big cavities, nearer equator (less curvature)



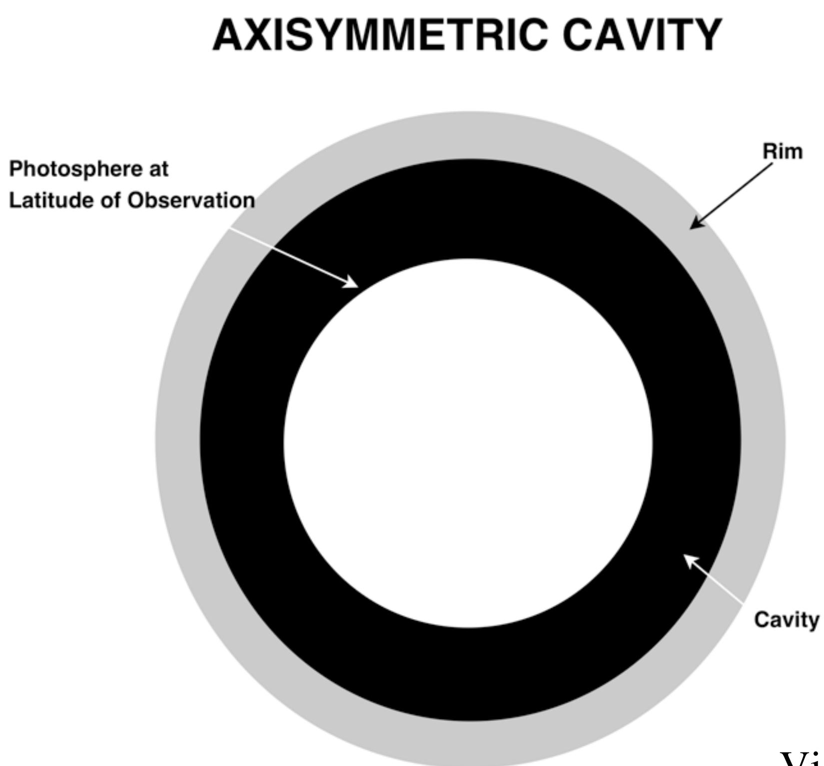
$$\alpha_{cav_c} = \pm \arctan \sqrt{\left(\frac{R_{cav}}{1+R_{cav}}\right)^2 + \frac{2R_{cav}\sin\theta_c}{1+R_{cav}}}$$

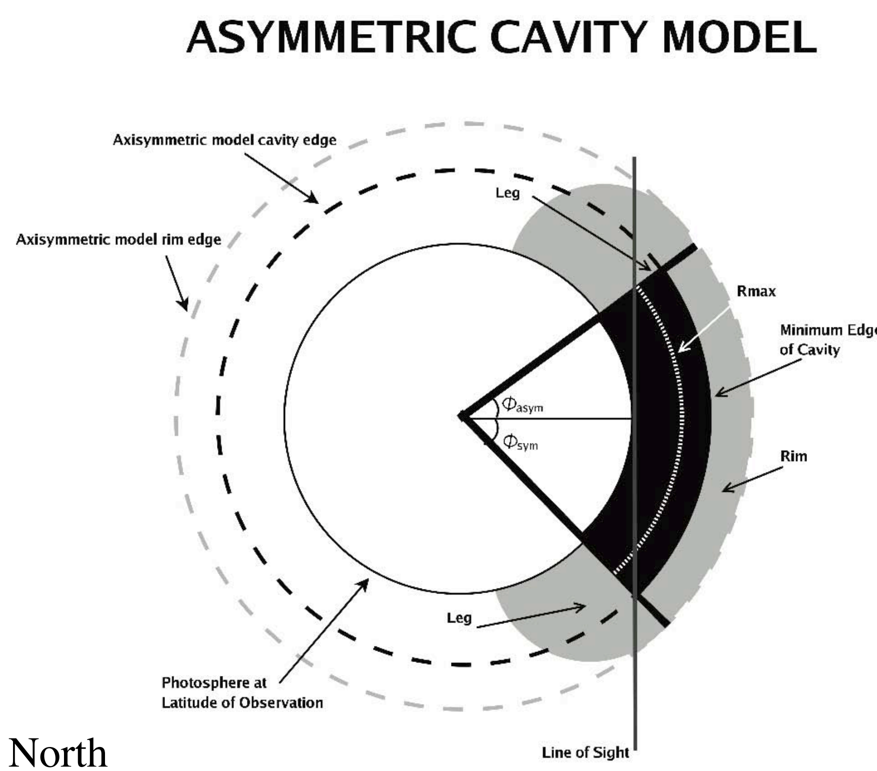




3D model geometry: best cavities for avoiding legs projection

- Only needs to be a torus for as long as line of sight passes through
- Better for higher plane-of-sky heights
- Better for small cavities (more curvature)

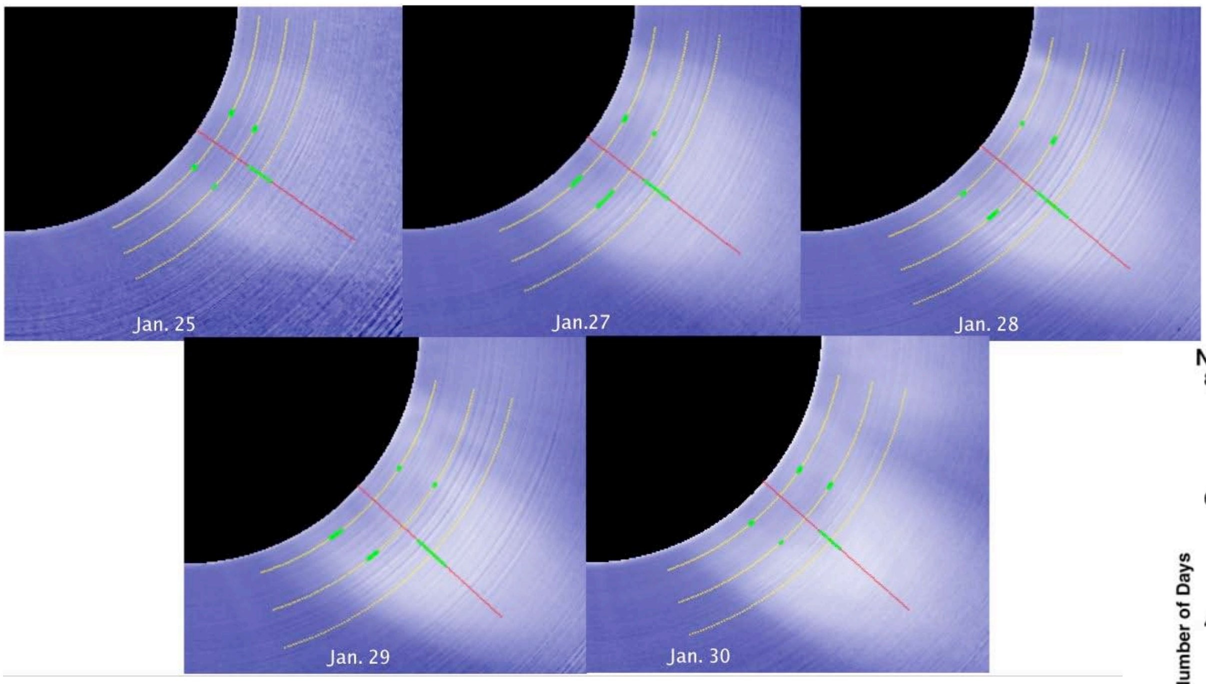




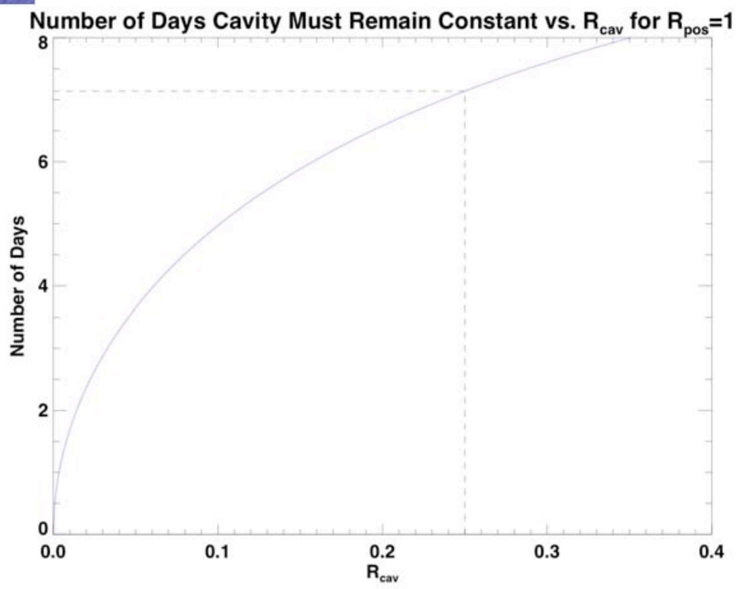
View from North

3D model: White light cavity that meets criteria

- Big enough (radius) for minimal rim projection
- Long-lived enough (longitudinal extent) for minimal leg projection



$$\phi_{sym_c} = \pm\arctan\left(2\sqrt{(R_{cav})^2 + R_{cav}}\right)$$

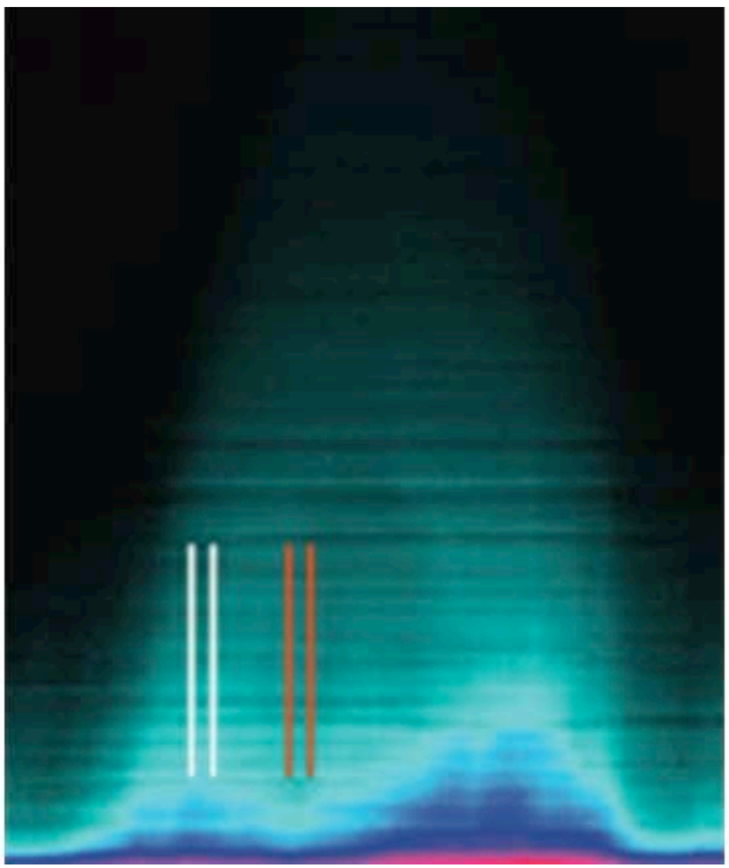


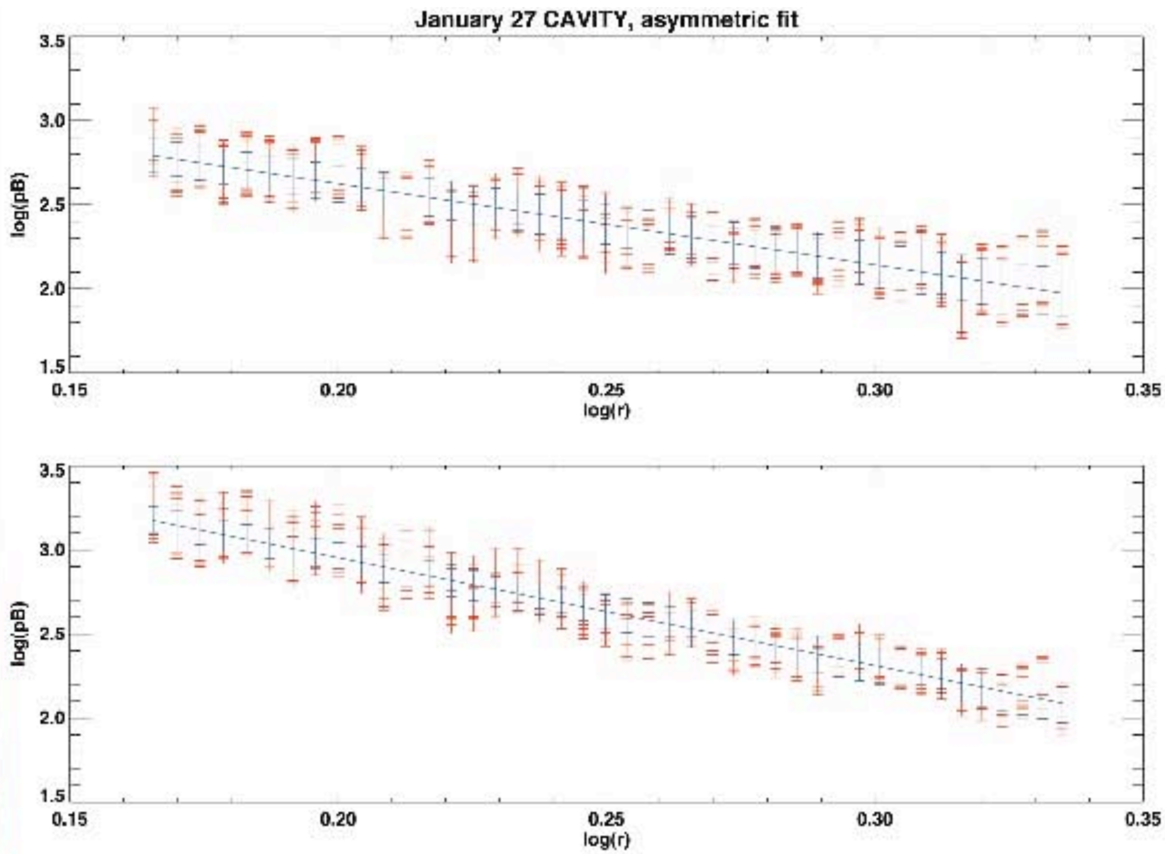
Calculating density from white light observations

- Include contributions from rim and legs as error bars

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

- Fit linear power law for polarized brightness vs. height

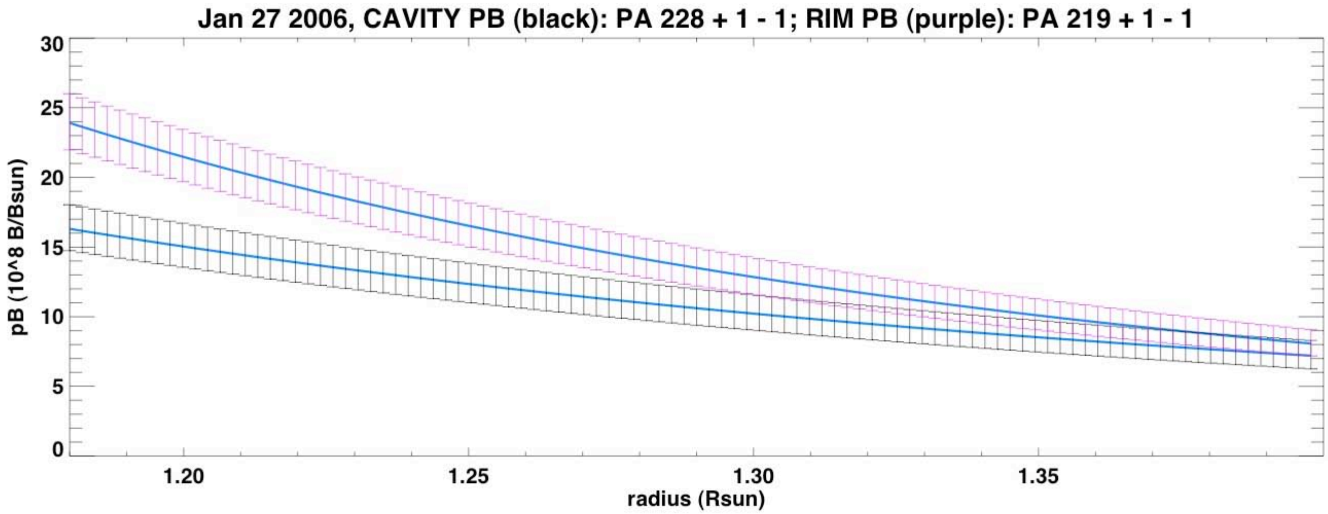


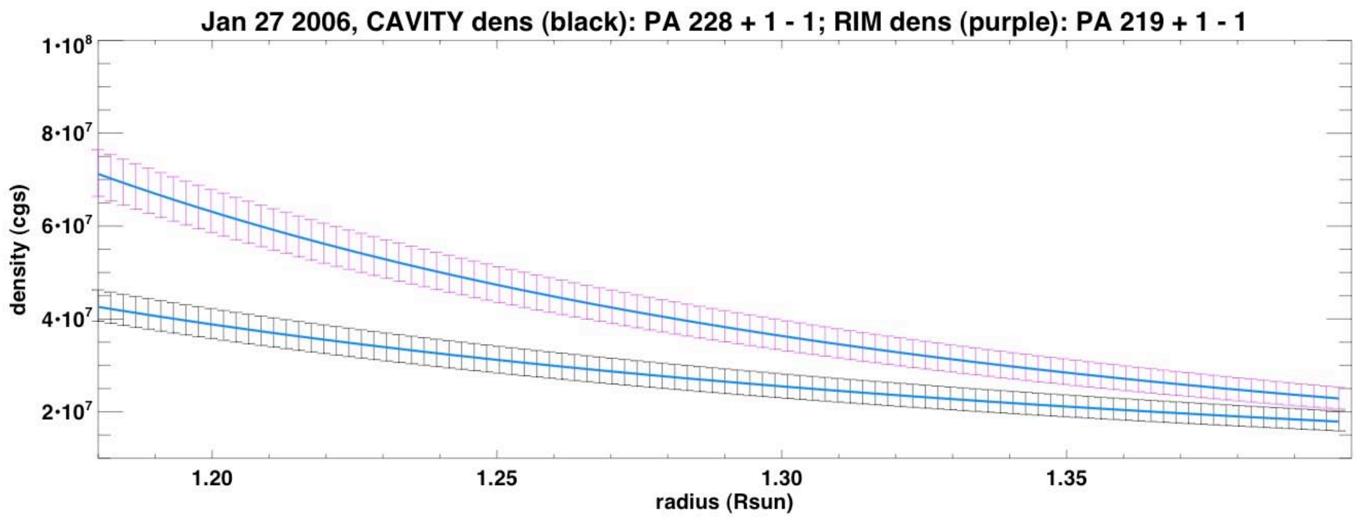


Calculating density from white light observations

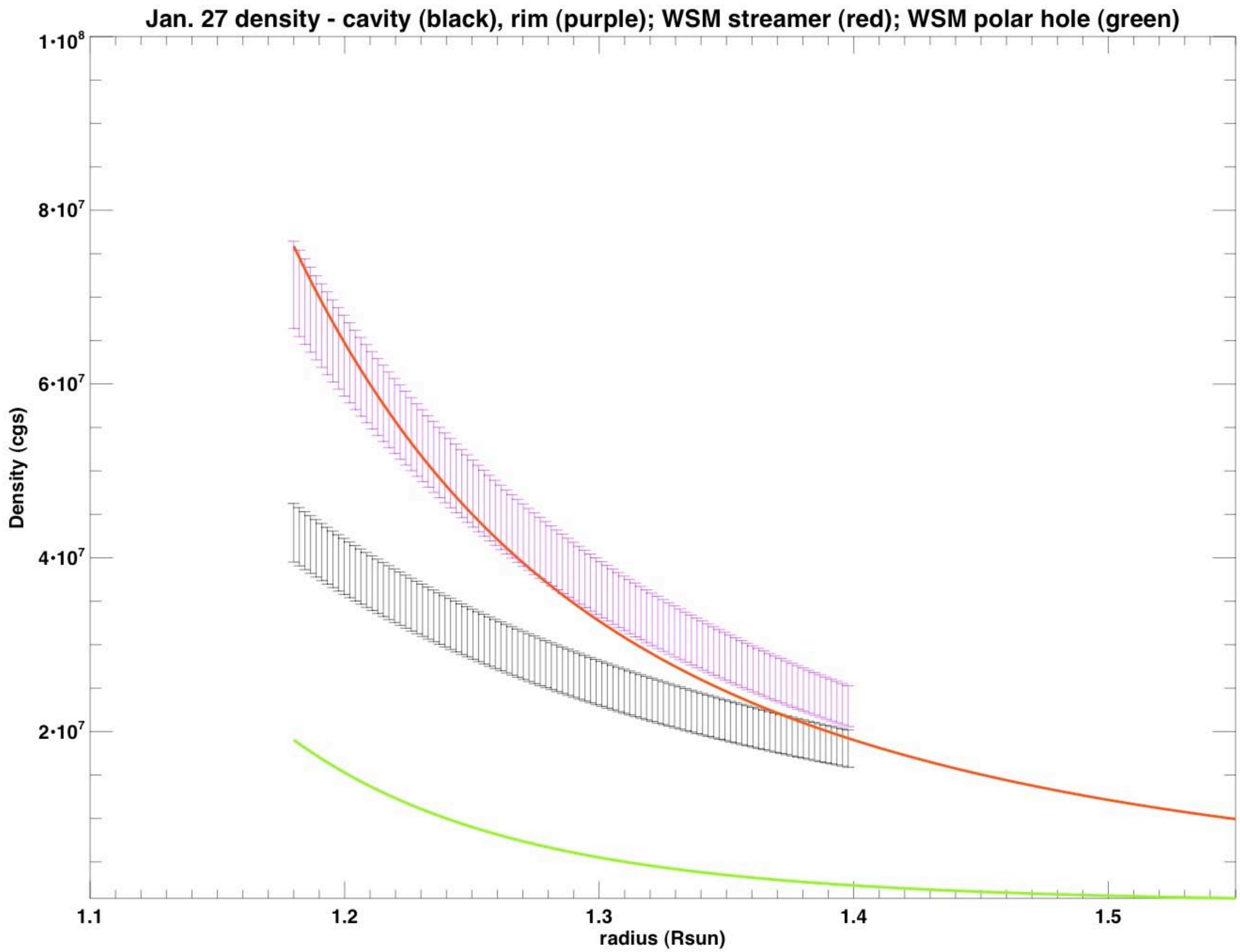
- Fit van de Hulst inversion to pB profiles to obtain density profiles

$$pB(R_{pos}, \theta_{pos}) = \int N_e(r, \theta, \phi) C(r) d\alpha$$





Calculating density from white light observations



1. Cavity density double or more than coronal hole density
2. Cavity density radial profile flatter than rim profile

Implications for cavity temperature/magnetic field

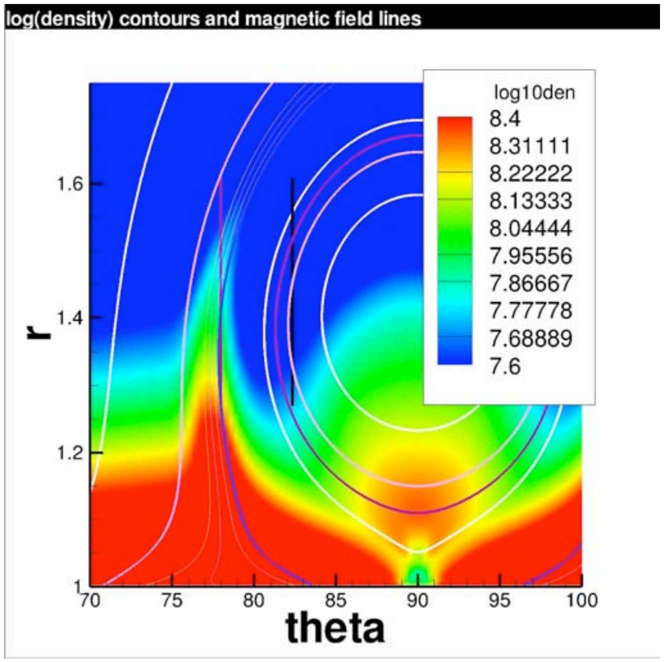
Possible **causes** of **flat density profile** in cavity:

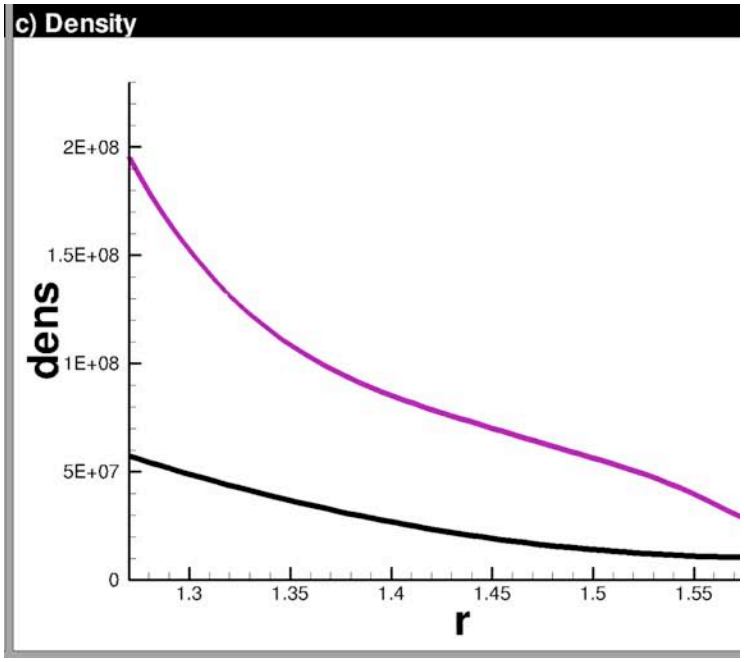
1) Temperature 21% hotter in cavity

- Fit density profile to hydrostatic profile, temperature is equivalent to scale height

$$N_{e_{fl}}(r) = N_{e_{fl}}(r_o) exp[\frac{1}{h_o r} - \frac{1}{h_o r_o}] \qquad h_o = \frac{kT}{C_{gas}} \frac{2+3\alpha_{He}}{1+2\alpha_{He}}$$

2) Magnetic flux rope (effectively) detached field lines *Fan and Gibson (2006)*

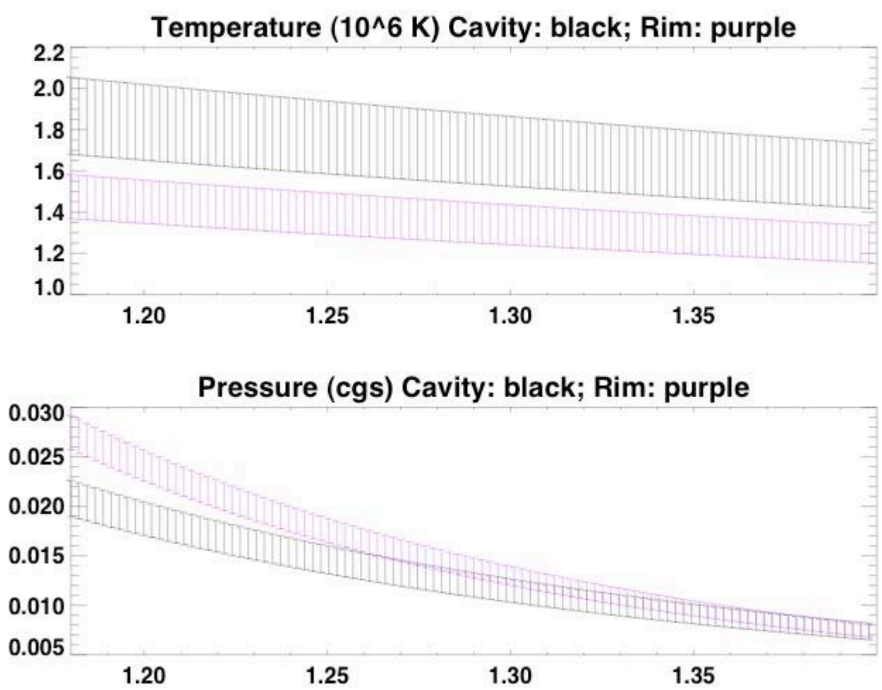




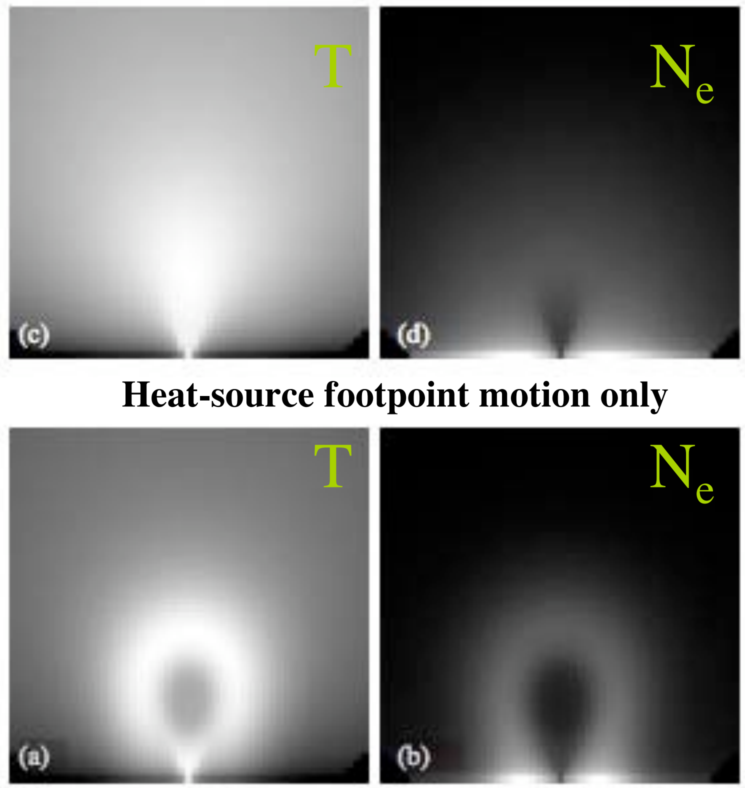
Implications for cavity temperature/magnetic field

Not mutually exclusive possibilities

- Some of the pressure balancing the bubble may be thermal, some magnetic
- If the cavity is hotter, it may be do to differences in heating arising from magnetic configuration



Van Ballegooijen and Cranmer (2008)



Hyperdiffusion also included

Density not enough!

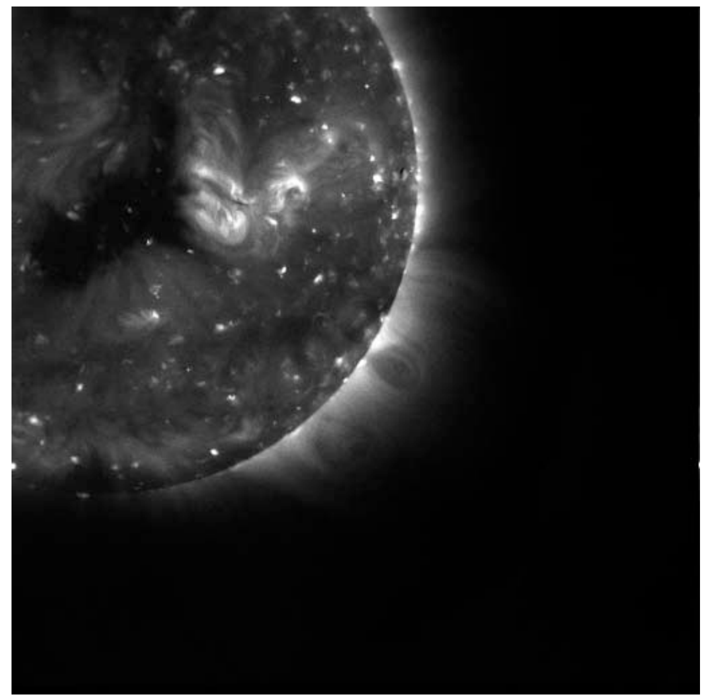
Need temperature, velocity, magnetic field diagnostics to distinguish between models

Cavities in emission

- Independent temperature diagnostics needed
- Geometry of model can also be used for emission cavities (generally easier-- need less days for effective axisymmetry, and emission falloff with height reduces contamination from cavity rim)
- When cavities well-resolved in emission, usually minimal overlap with white light (eclipse would be ideal!) -- however, with enough spectral resolution density and temperature can be probed via emission

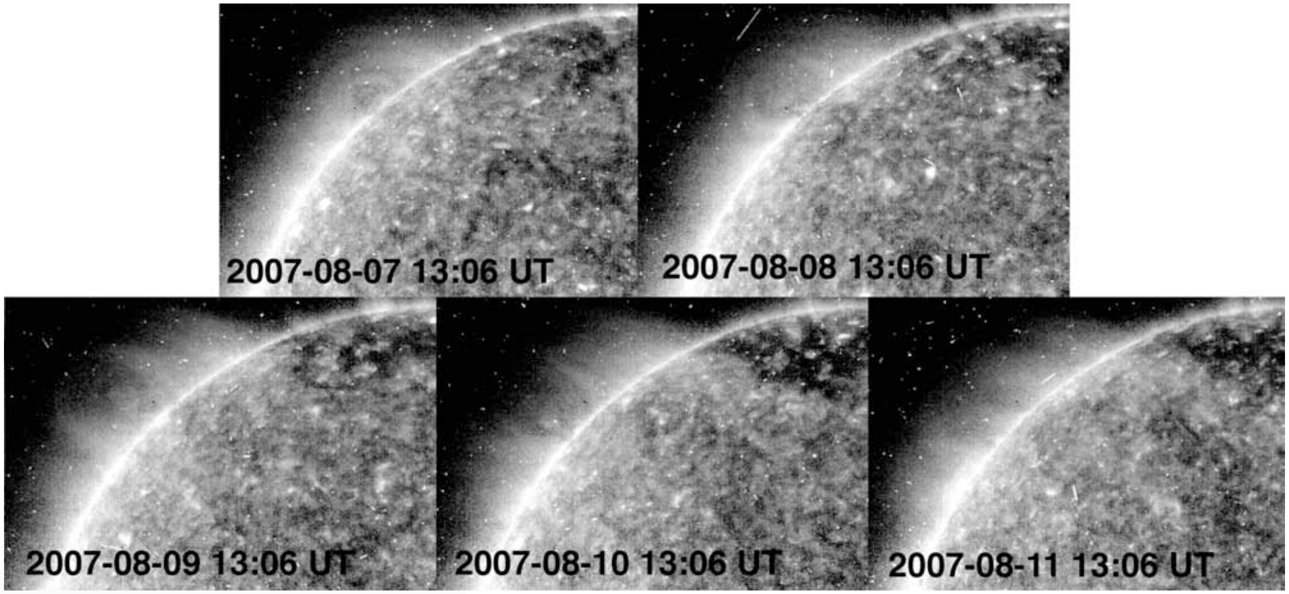
We have begun a series of campaign observations

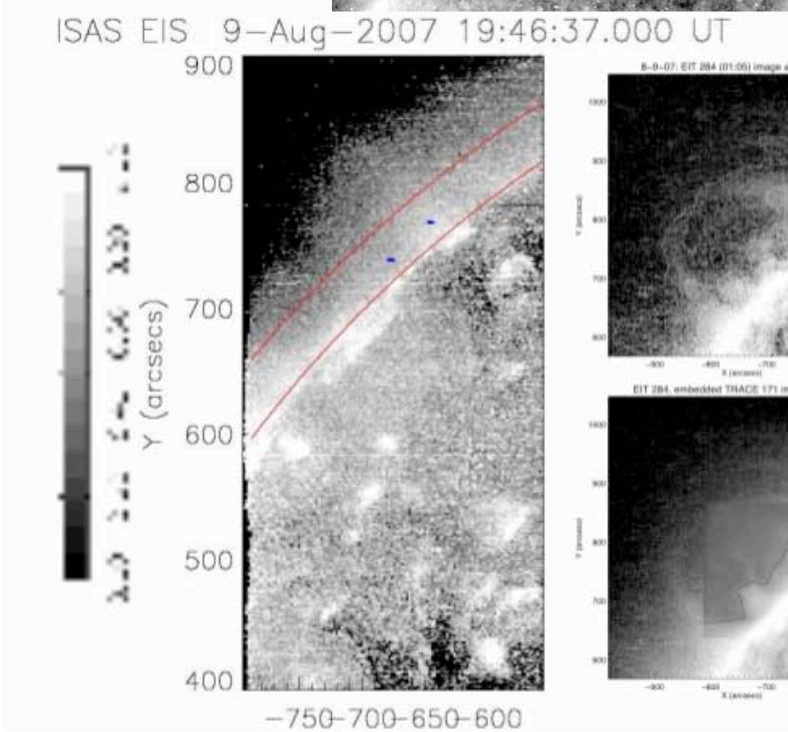
Mk4 white light

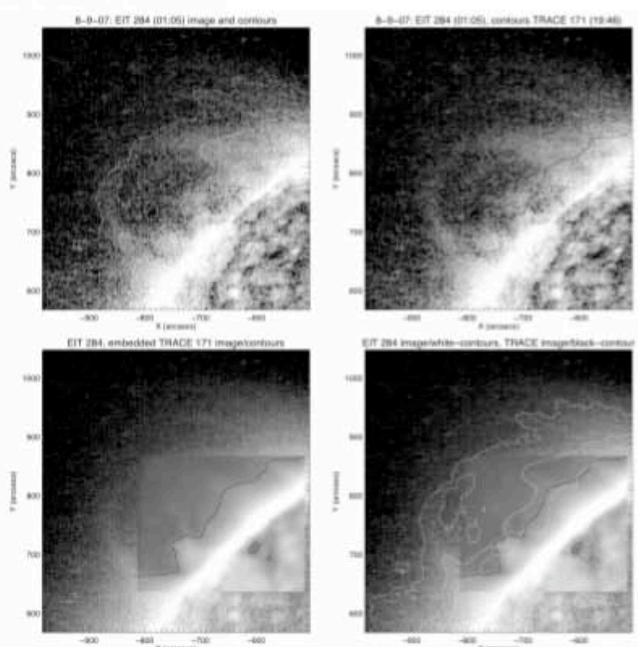


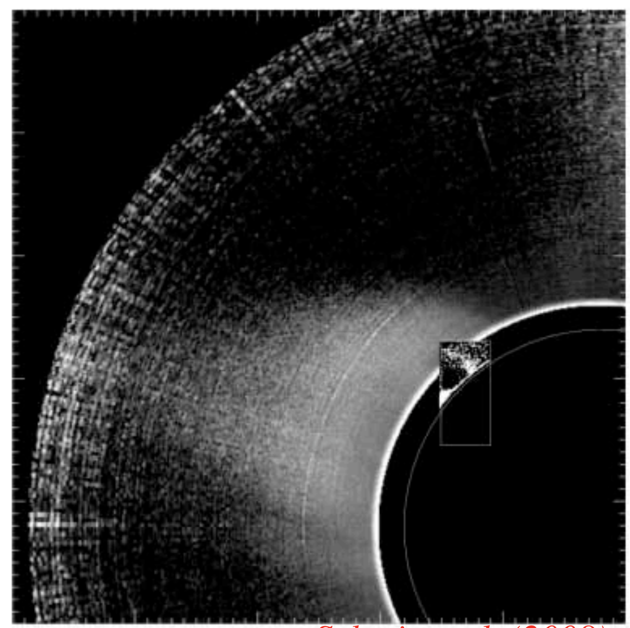
Hinode XRT

Cavities in emission: August 9, 2007 *(Schmit et al, 2008)*





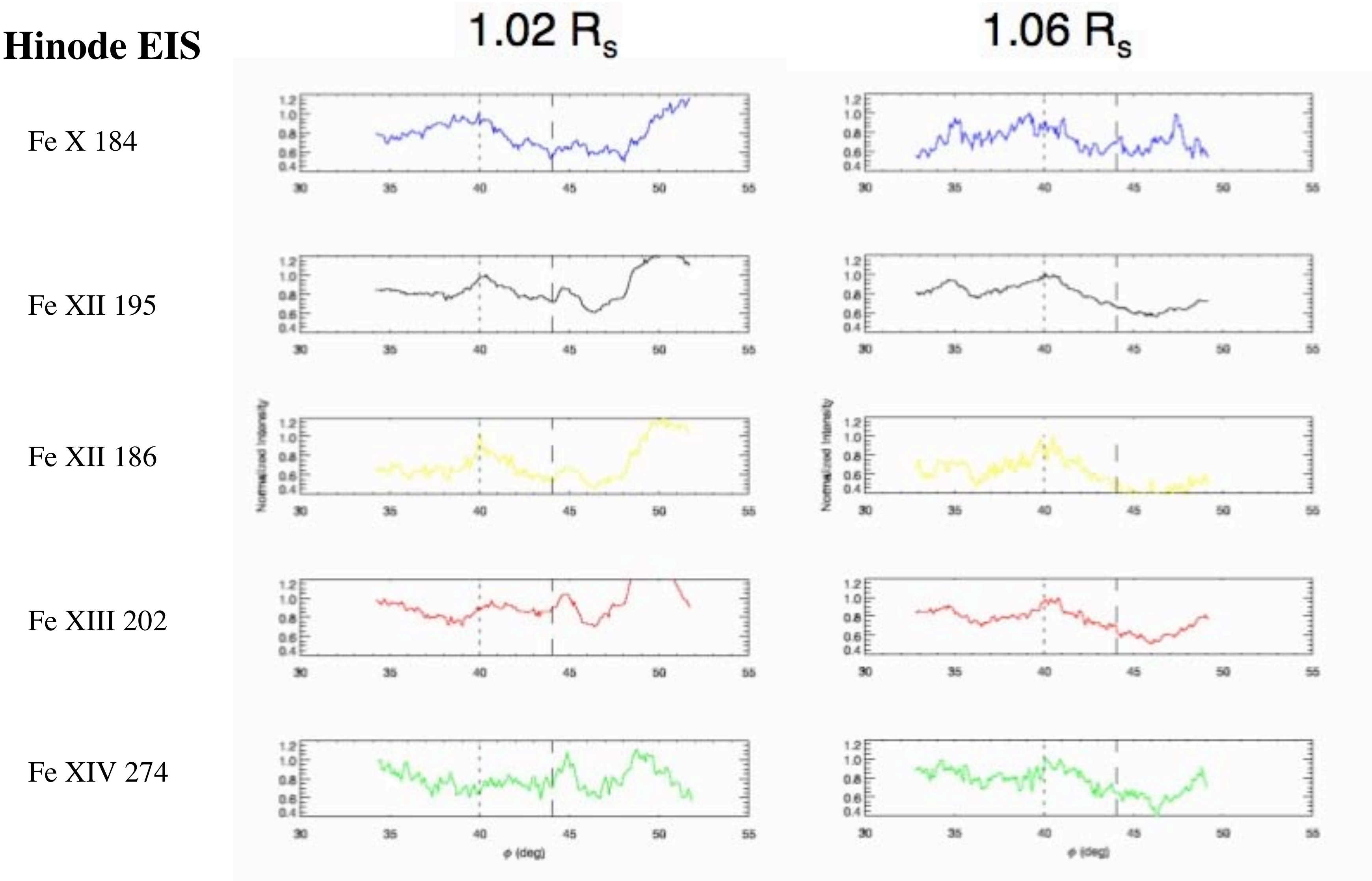




Schmit et al. (2008)

Cavities in emission: August 9, 2007

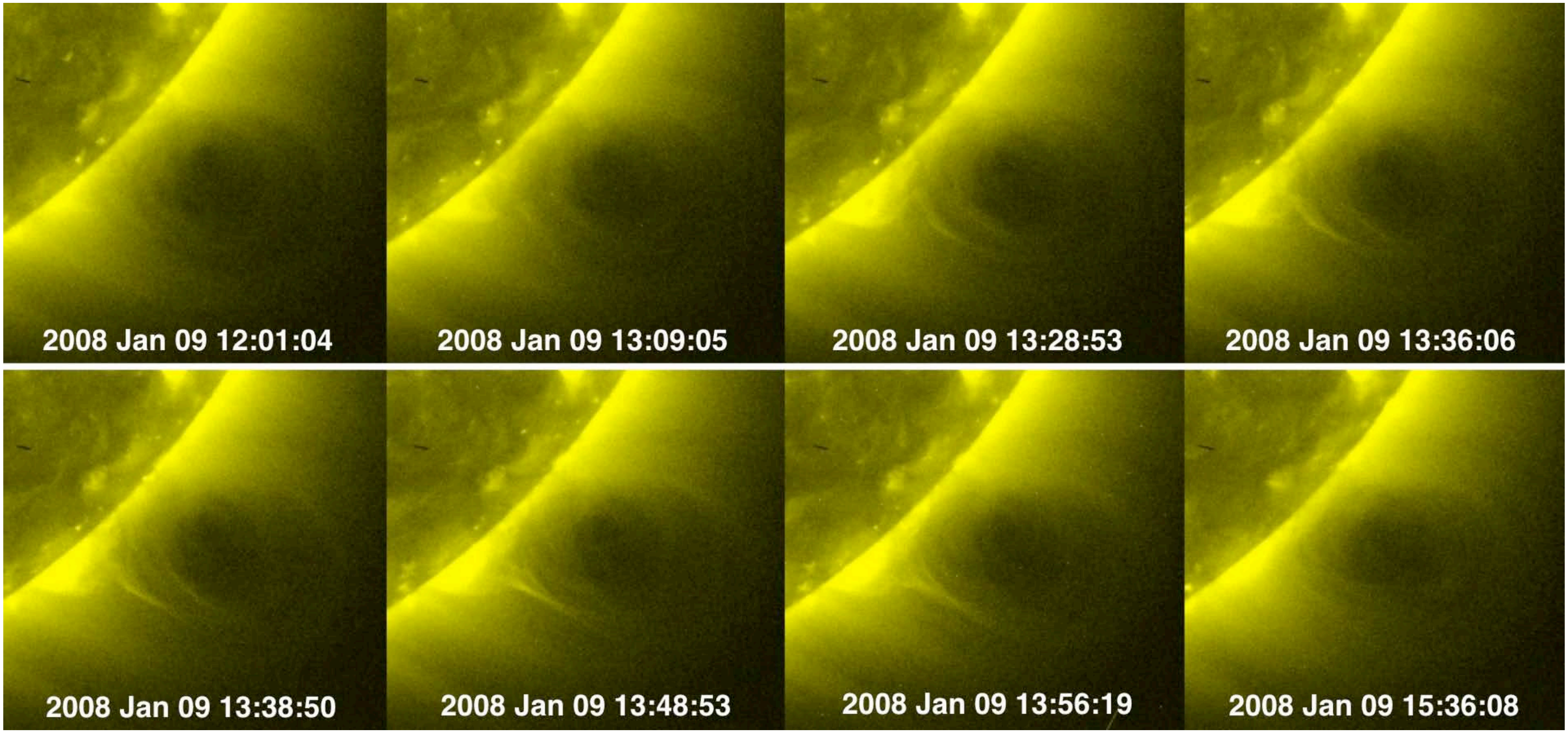
Hinode EIS



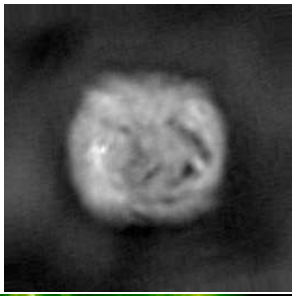
- Delta-intensity between cavity and rim less for hotter lines
- Cavity hotter than rim? DEM and EM Loci methods seem to agree (preliminary!)

Cavities in emission: January -- July 2008

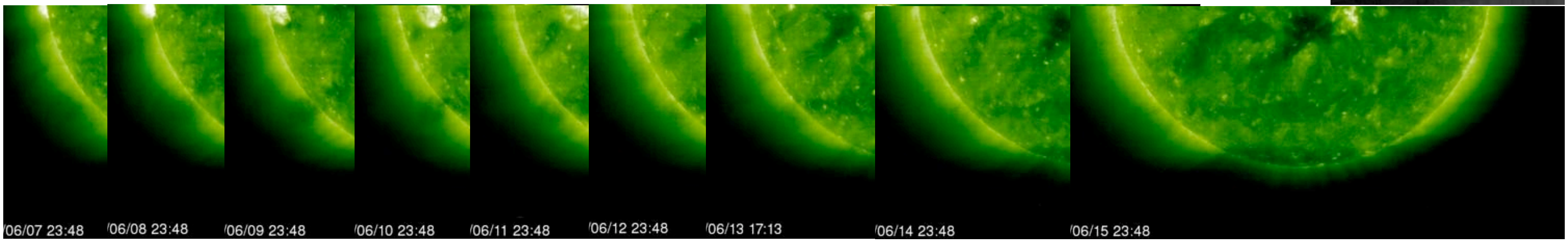
Hinode XRT



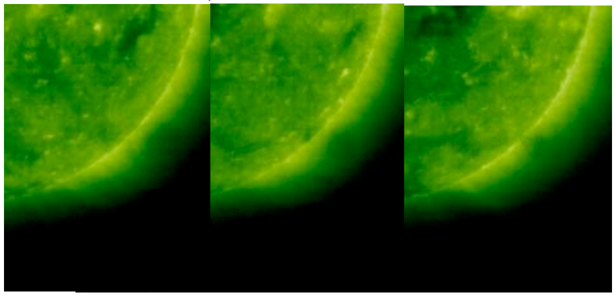
Cavities in emission: January -- July 2008



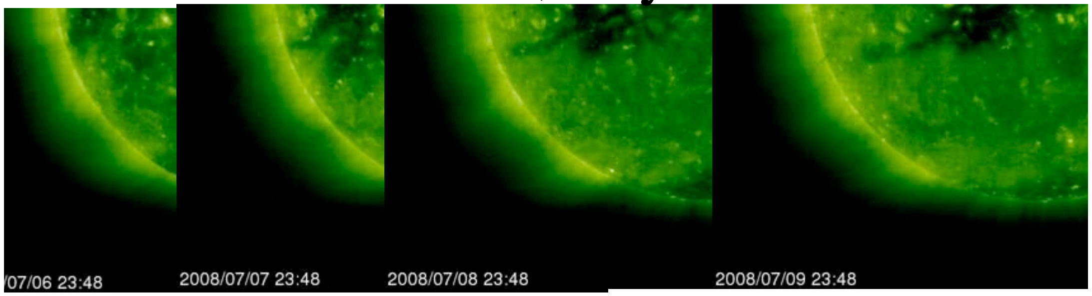
West limb, June 7-15 2008



East limb, June 22-24 2008



West limb, July 6-9 2008

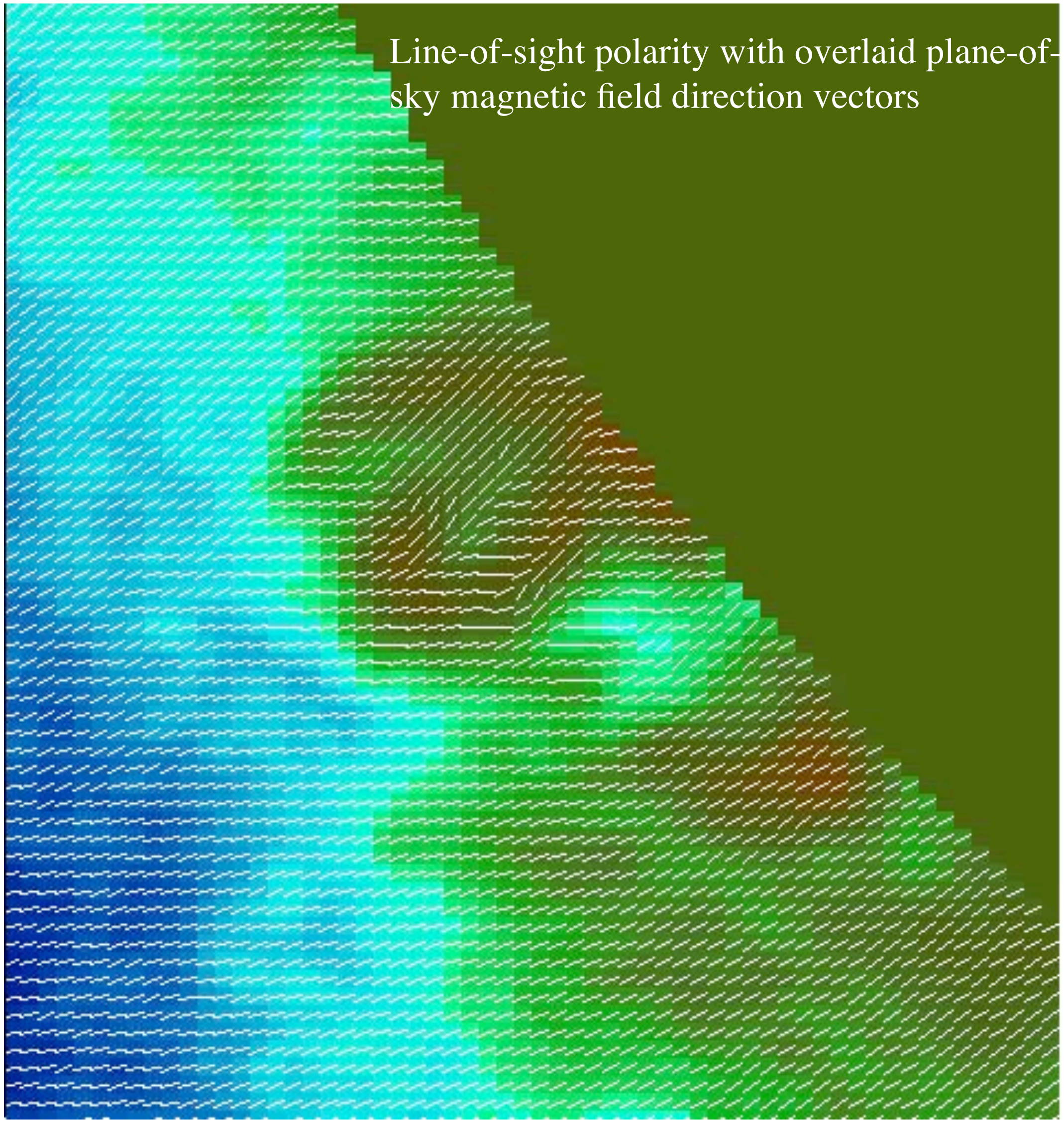


- Geometry very well-constrained (parallel to equator, 3D STEREO views)
- Multi-spectral observations (EIS, XRT, CDS, EIT, TRACE, …) taken April 1-2, 16; June 24, 26; July 3-6; July 19-23
- Polar crown filament eruptions July 12-14, however!
- Unprecedented opportunity to study thermal, morphological, and evolutionary properties of cavities

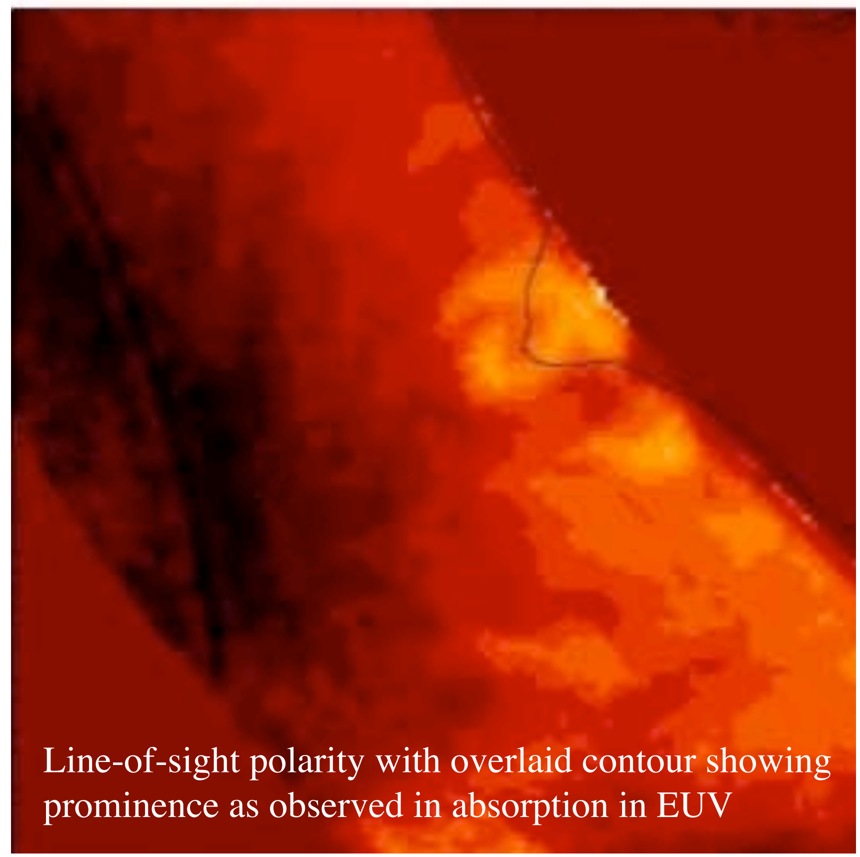
Can we observe magnetic field more directly?

Coronal Multi-channel Polarimeter CoMP observations:

Infrared **observations** of **coronal magnetic fields and line-of-sight velocity**



Courtesy S. Tomczyk



Conclusions

- Are cavities unobservable? No!
  - Projection effects of unrelated material can be dealt with
  - Cavity plasma significantly denser than corona hole
- White light observations indicate cavity density profile flatter than rim
- Preliminary emission observations indicate cavity hotter than rim
  - Further diagnostics needed to pin down temperature, velocity, density structure and constrain magnetic models
- Models also need to explain:
  - Circular cross-section and sharp boundary
  - Observations of cavity rising, getting more sharply defined in the 24 hours before a CME: possible indicator of magnetic energy reaching a critical threshold for eruption?