Small-scale evolution of coronal holes

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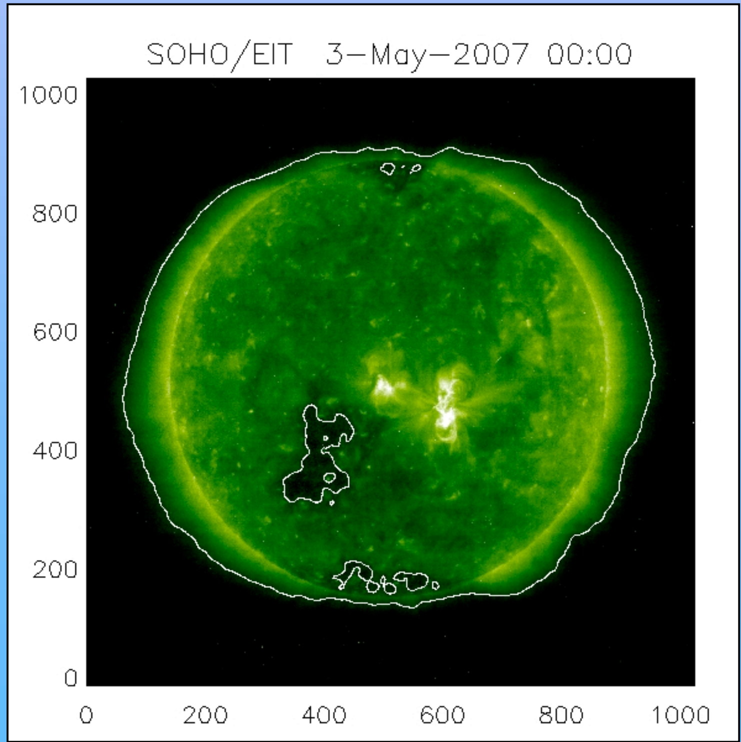
Outline

- How do we detect coronal holes?
- Are there short-term changes in coronal holes?
  - How do we detect it?
  - What is the physical mechanism?
  - What effect does the quiet Sun have?
- What information can we get from short term CH evolution?
  - Diffusion coefficient
  - Magnetic reconnection rate

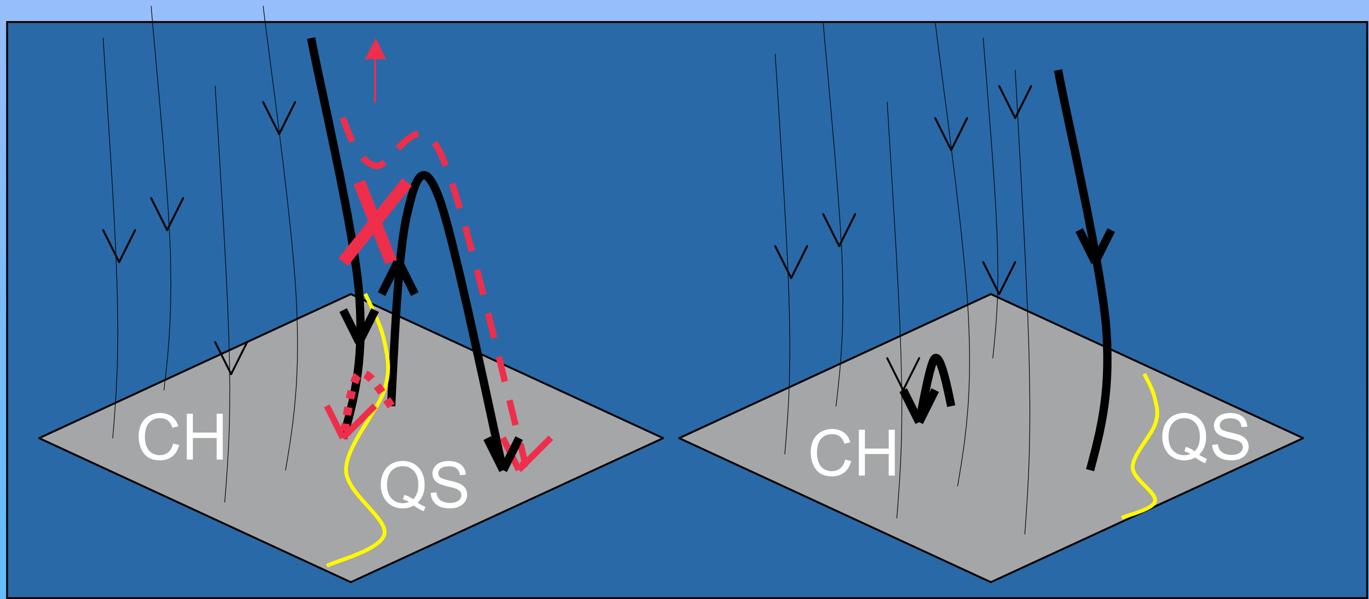
Coronal Holes

- Open magnetic field lines - extending from photoshpere through Heliosphere
- Source of high-speed solar wind
- Density ~ half of quiet Sun
- Temperature ~ 1 MK
- Types: polar, isolated, transient
- Lifetime: days - months
- Best visibility: X-ray, EUV



Small scale CH evolution

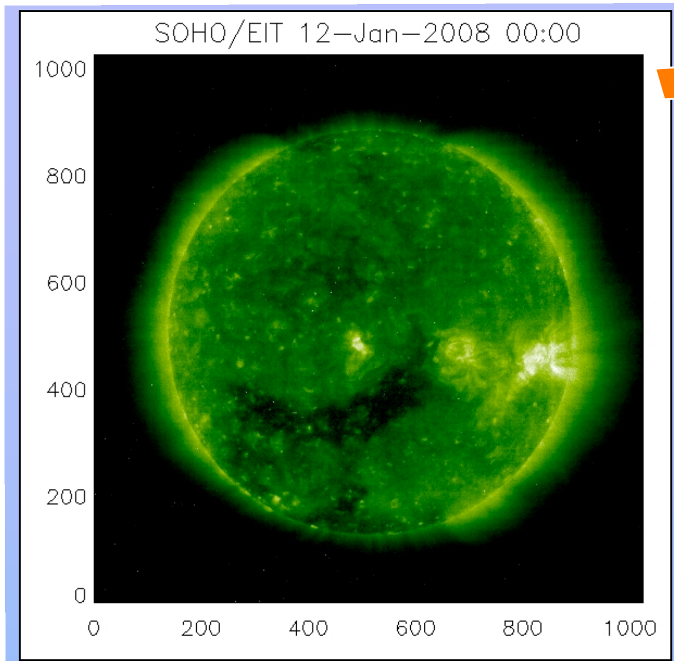
- Interchange reconnection along CH boundaries
  - Low number of large loops inside CHs
  - Could explain expansion of CHs
  - Explains rigid rotation of CHs



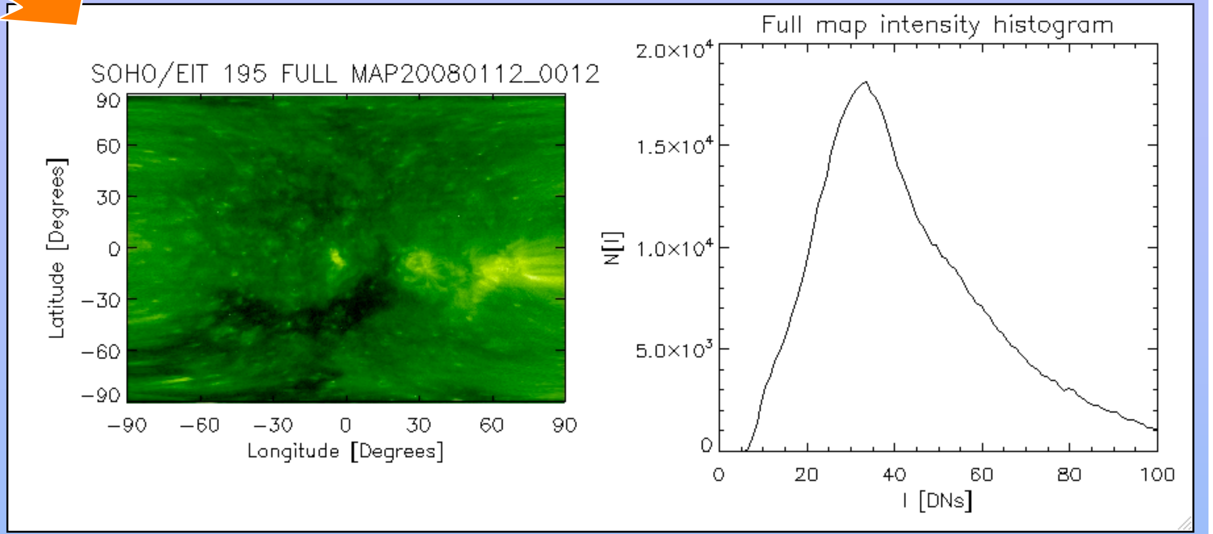
(based on Fisk & Zurbuchen, 2005)

Automated coronal hole detection

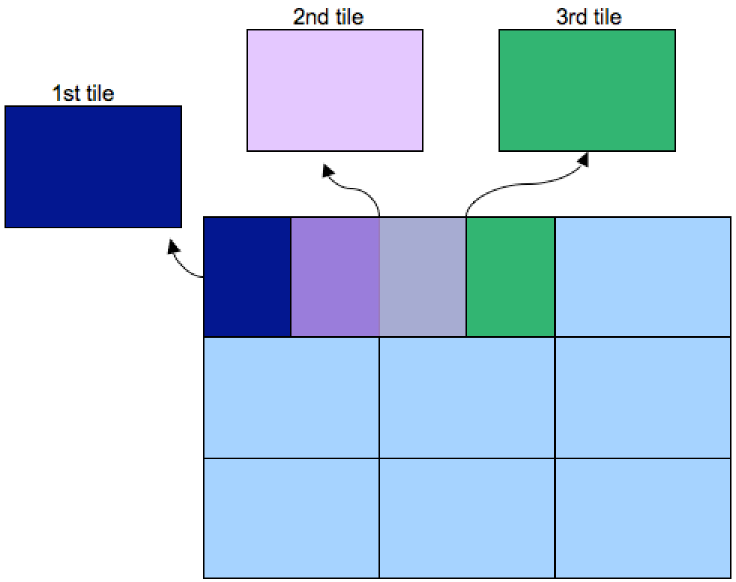
- Observations
  - SOHO/EIT, STEREO/EUVI (195 A) and Hinode/XRT
  - SOHO/MDI magnetograms - differentiating coronal holes from filaments
- Local intensity thresholding technique
  - Krista & Gallagher, Solar Physics, 2009



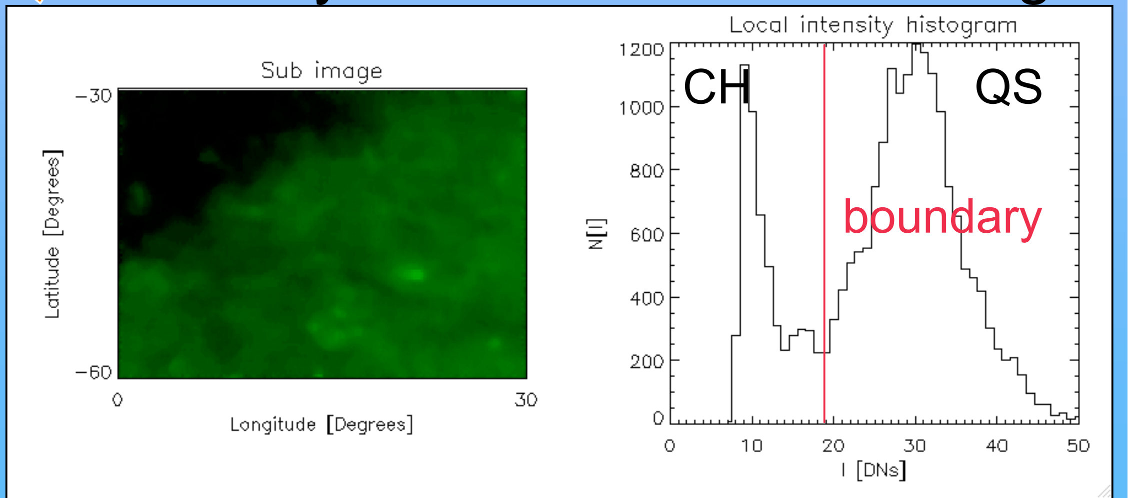
Lambert projection map



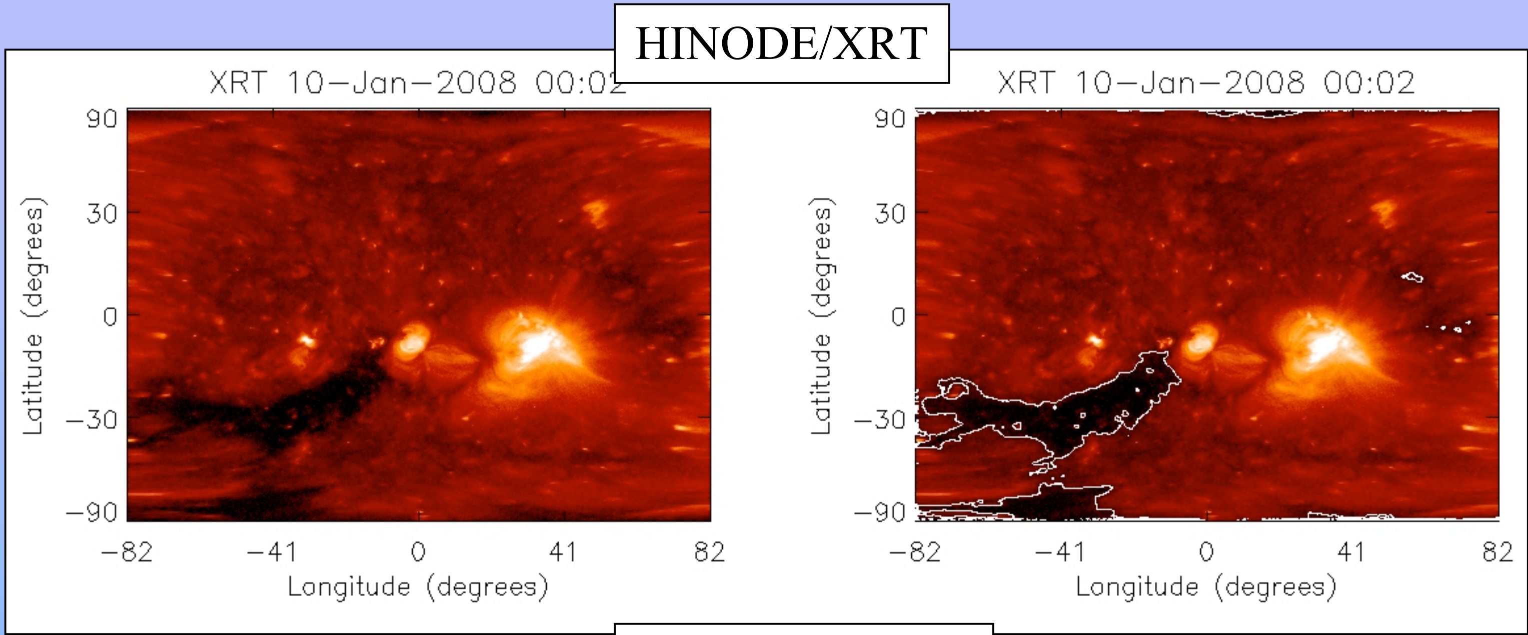
Step-wise image partitioning

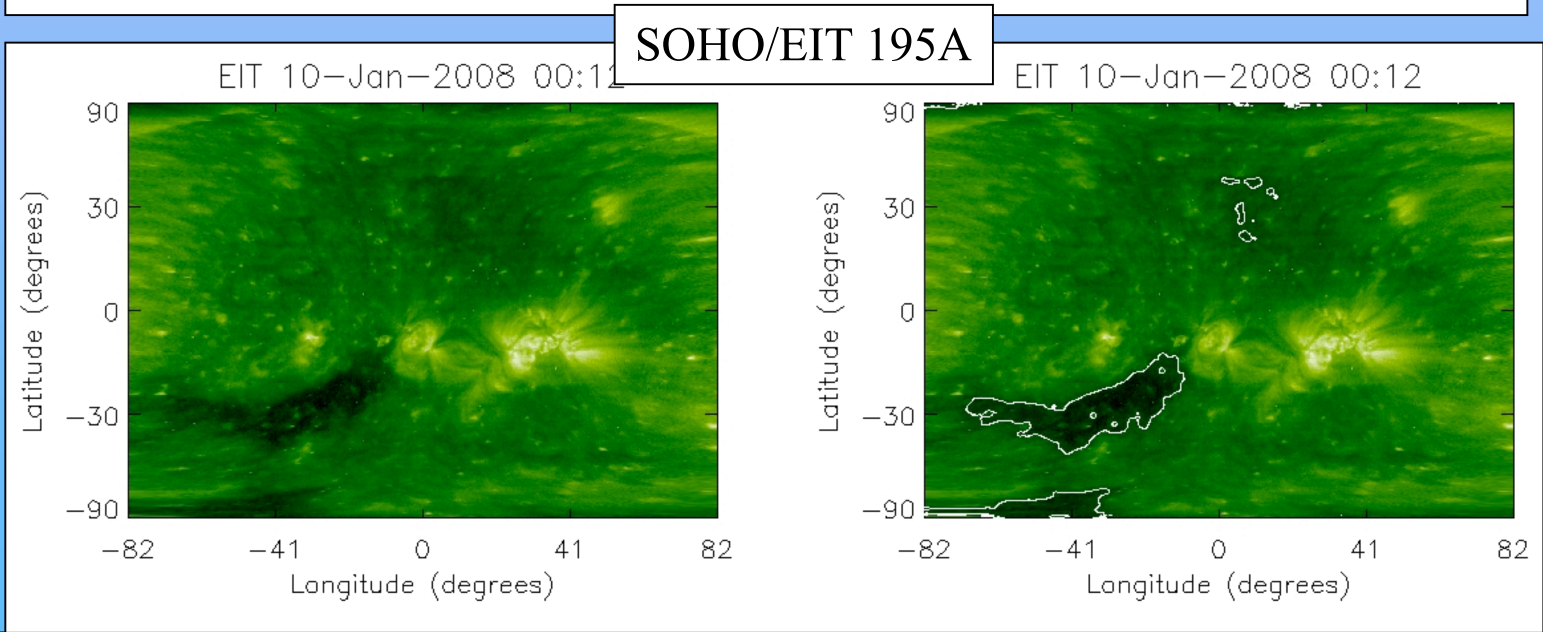


Intensity threshold from sub-images

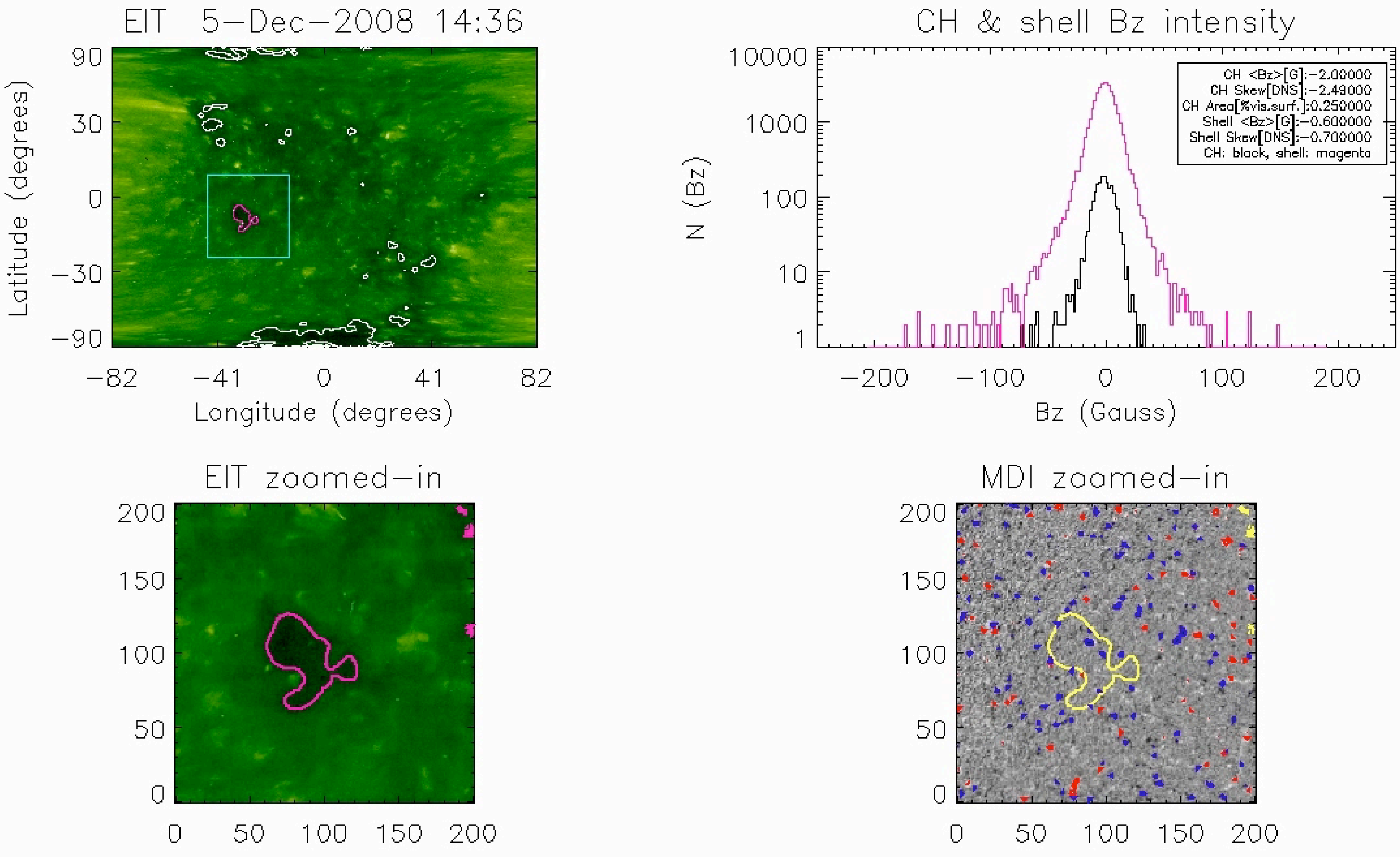


Resulting coronal hole maps

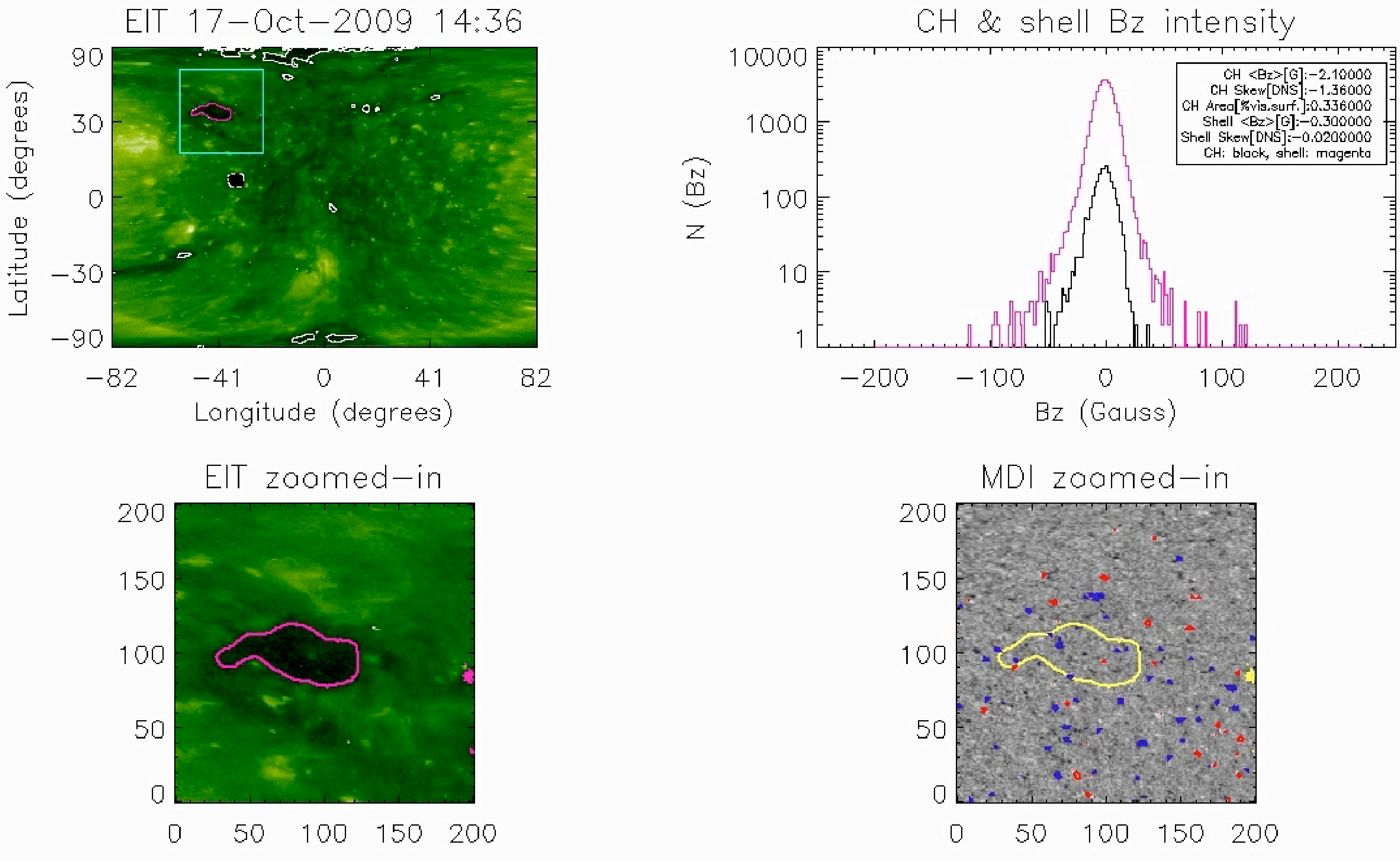




Coronal hole and its magnetic field

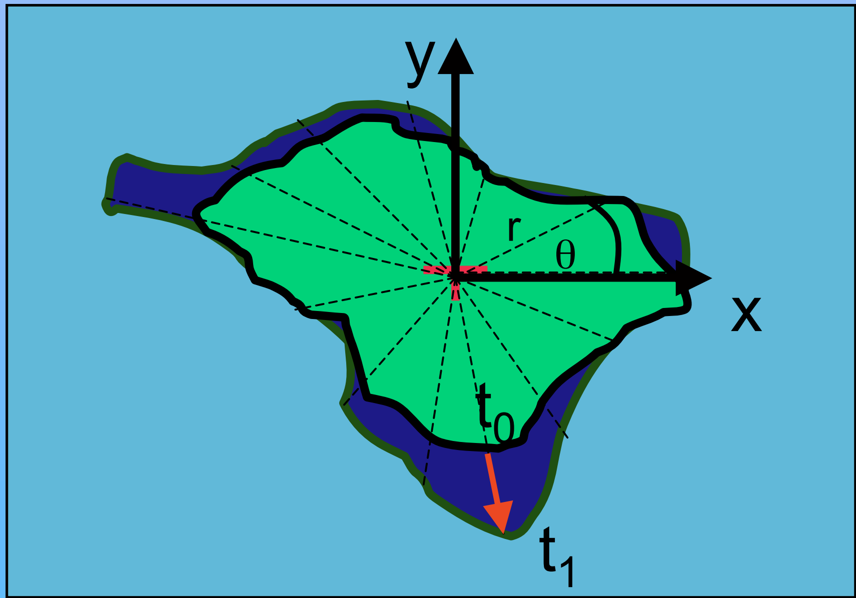


Coronal hole and its magnetic field

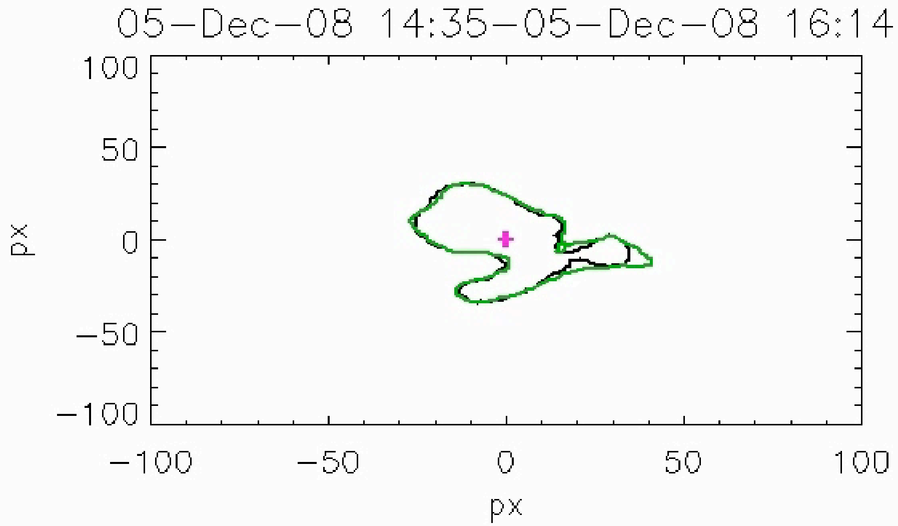


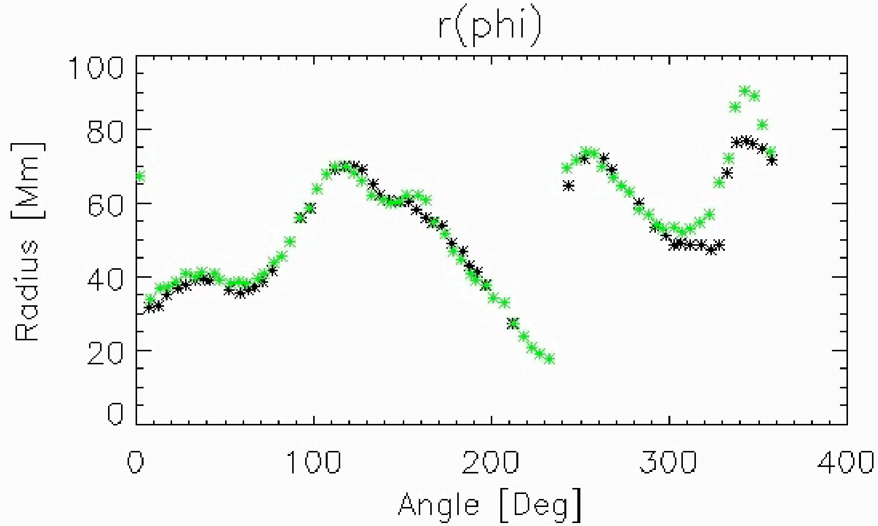
CH boundary tracking

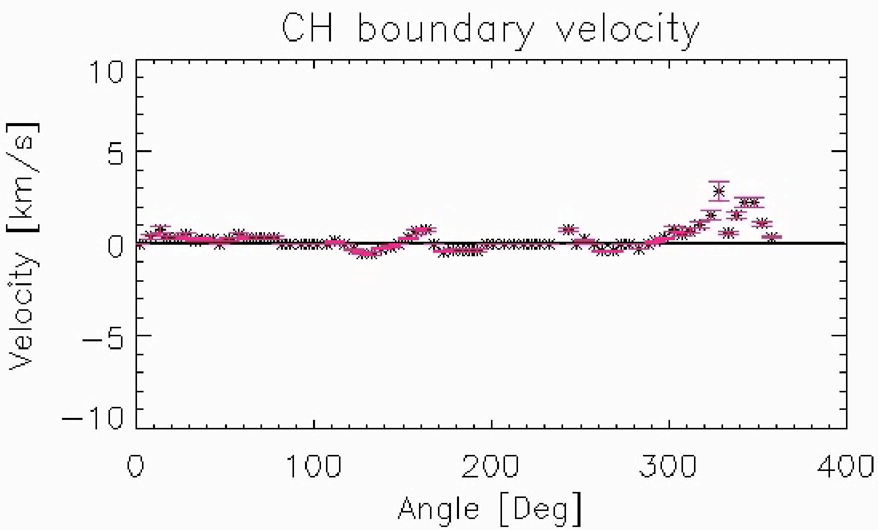
- Transform rectangular coordinates to polar, average over integer degrees
- Determine boundary distances from the CH centroid for t_0 and t_1
- Determine the velocity of the boundary relocations



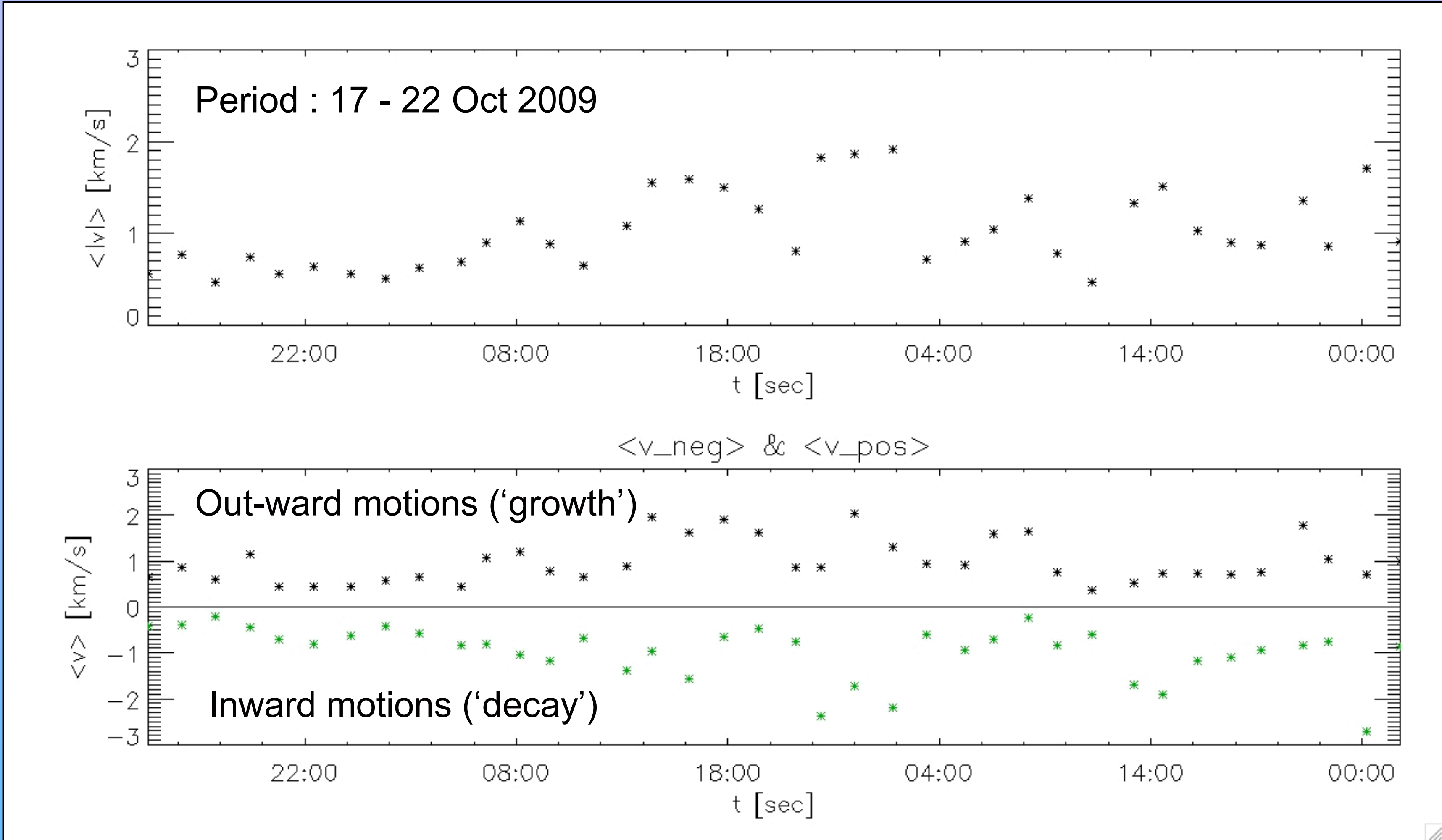
Relocation and velocity plots







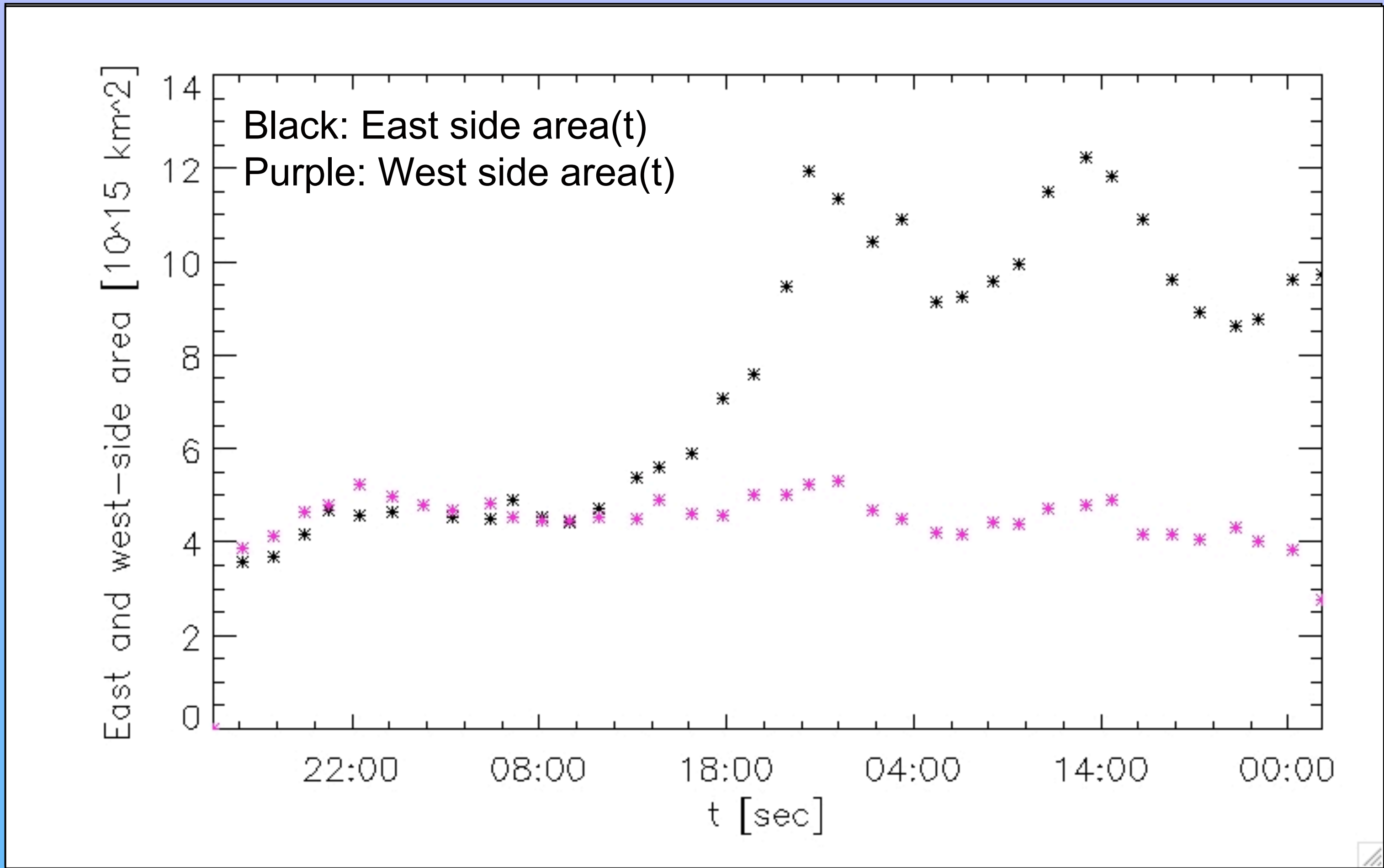
Velocity plots



For $v_{max} = 8 - 13$ km s^{-1} $M_0 = v_{max} / v_{Alfven} = 0.008 - 0.013$

$\langle v \rangle = 0.8 - 1$ km s^{-1} $M_0 = \langle v \rangle / v_{Alfven} = 0.0008 - 0.001$

Does differential rotation effect CH growth?



Differential rotation - constant supply of loops on **East side of CH**

Magnetic diffusion

- Diffusion rate

  (Wang, Sheeley & Lean 2000, Fisk & Schwardon 2001)

$$\frac{\partial B_r}{\partial t} = \kappa \nabla_s^2 B_r - \nabla \cdot (u_s B_r)$$

$$\kappa = \frac{(\delta h)^2}{2\delta t}$$

- Observed relocation distances: dr_{max} ~ 40 Mm

  <dr> ~ 2 Mm   ($\delta t \approx 6000$ s)

- At CH boundary $\kappa_{max} \approx 1.2 - 1.4 \times 10^{15}$ cm^2 s^{-1}

  $\langle\kappa\rangle \approx 3.3 - 5.3 \times 10^{12}$ cm^2 s^{-1}

Fisk & Schwadron 2001 :

In CH: $\kappa = 3.5 \times 10^{13}$ cm^2 s^{-1}

In QS: $\kappa = 1.6 \times 10^{15}$ cm^2 s^{-1}

Conclusions

- New automated methods
  - Robust detection of CHs at multi-wavelengths
  - Detection of CH boundary displacements
- East-side directional preference in CH area growth
  - Due to differential rotation supplying loops and enhancing interchange reconnection
- Magnetic field diffusion through interchange reconnection at CHs boundaries: 1.2 - 1.4 x 10^{15} cm^2 s^{-1}
- Magnetic reconnection rate determined from observations $M_{max} \approx 0.008 - 0.013$