Polar Plumes:

What has changed since the last solar minimum?

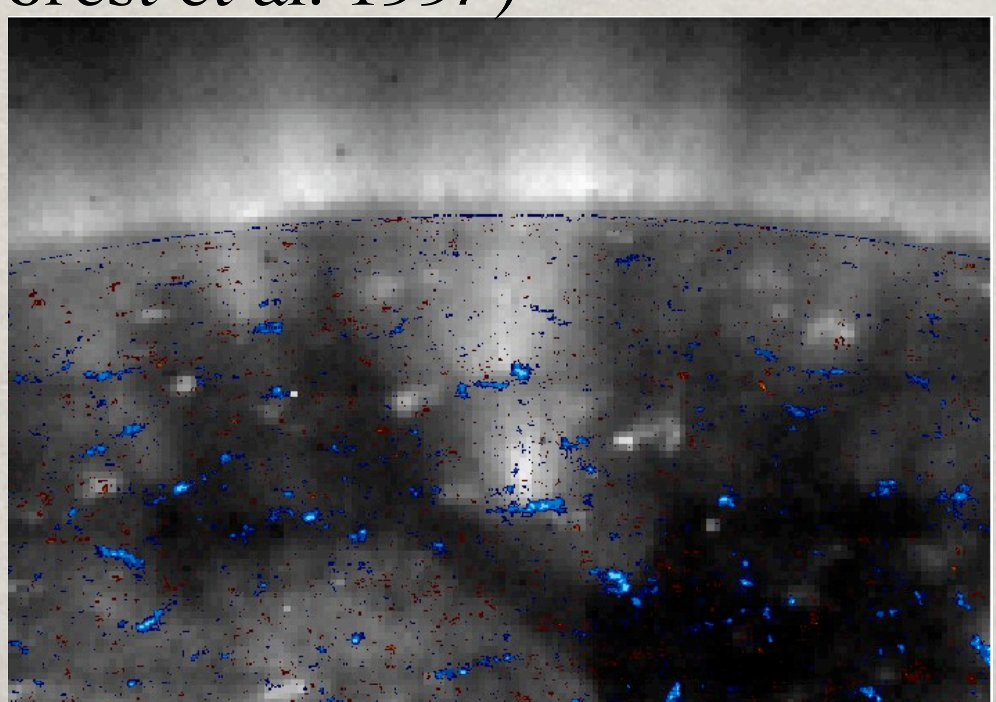
C. DeForest
Cycle 24 Meeting
Napa, Ca
9-Dec-2008

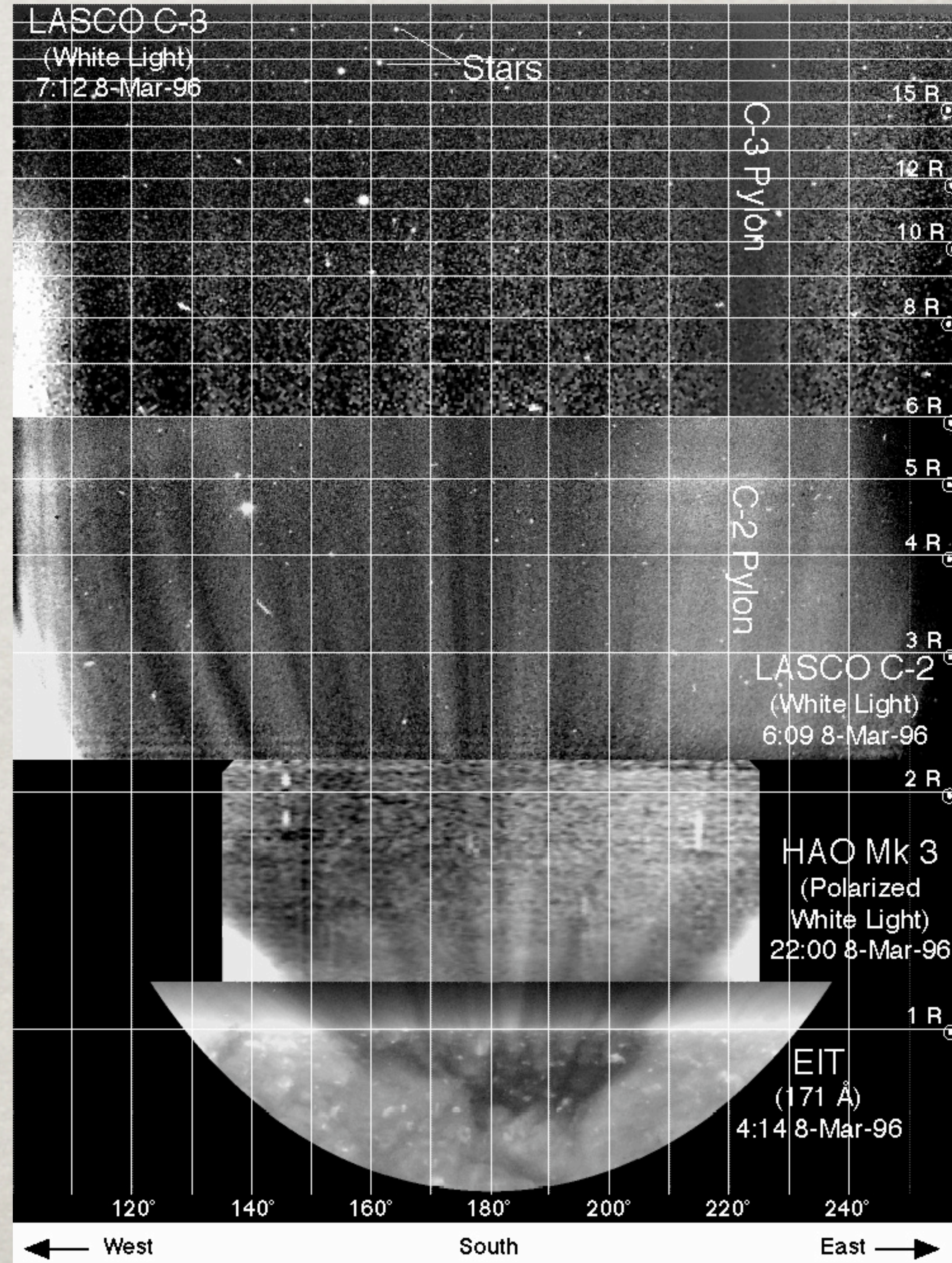
Plume morphology

Plumes:
- arise from nearly unipolar, mixed polarity regions in the coronal hole;
- form EUV-bright features that merge into bright white-light features ("coronal rays") in the mid to outer corona;
- last about a day

(Saito 1965, Harvey 1965,
Fisher & Guhathakurta 1995,

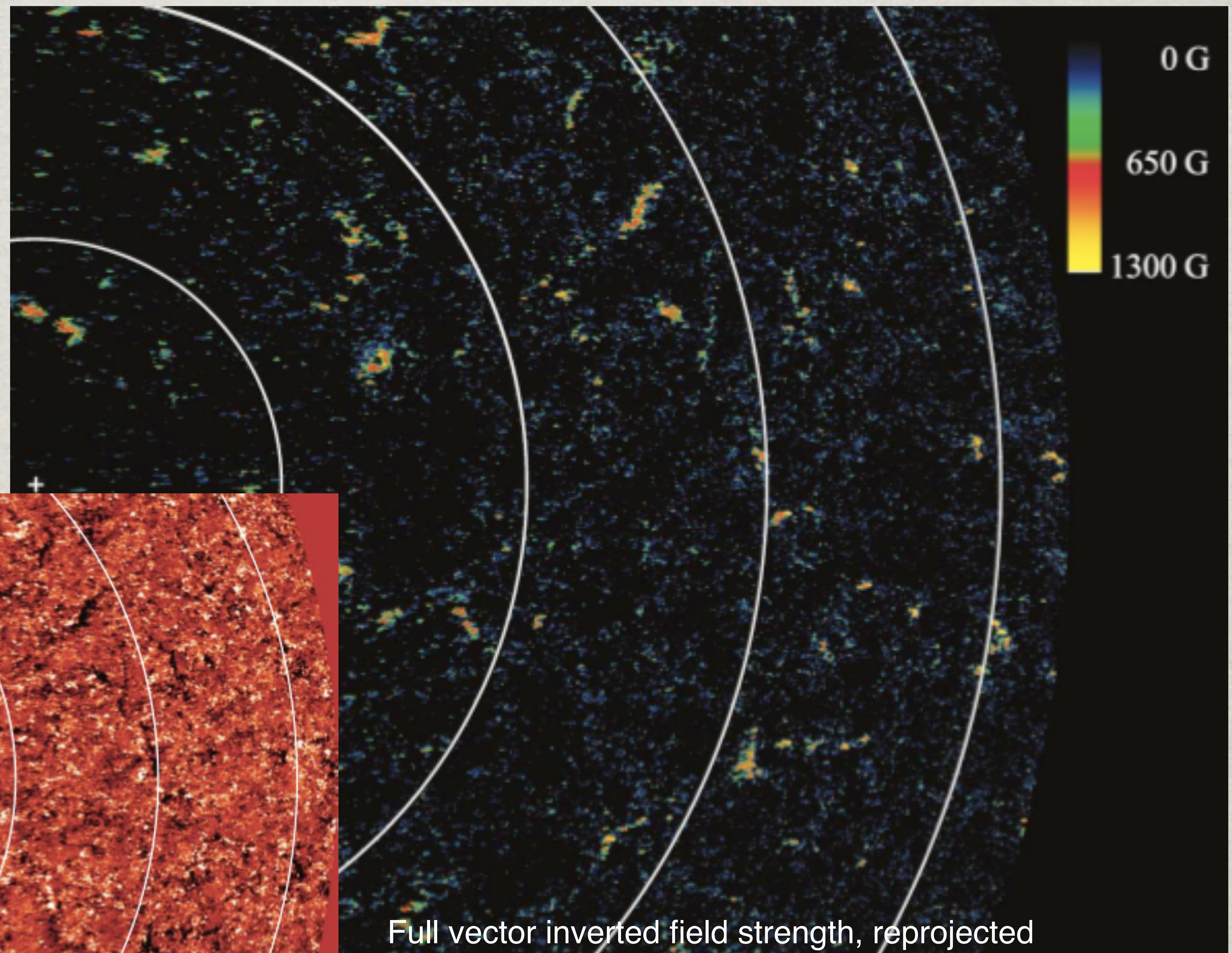
DeForest et al. 1997)



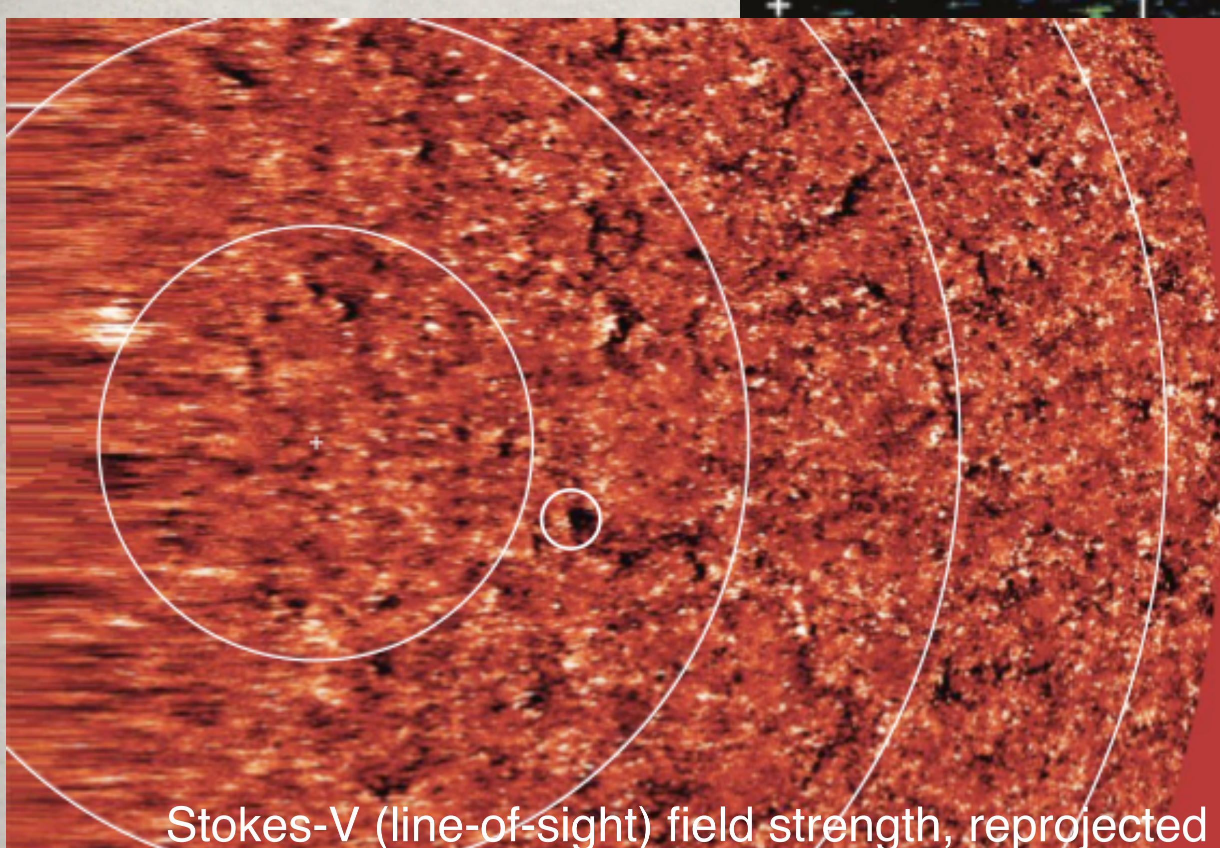


Magnetic Structure

Higher resolution *vector* magnetograms now available from Hinode (Tsunetaet al. 2008)

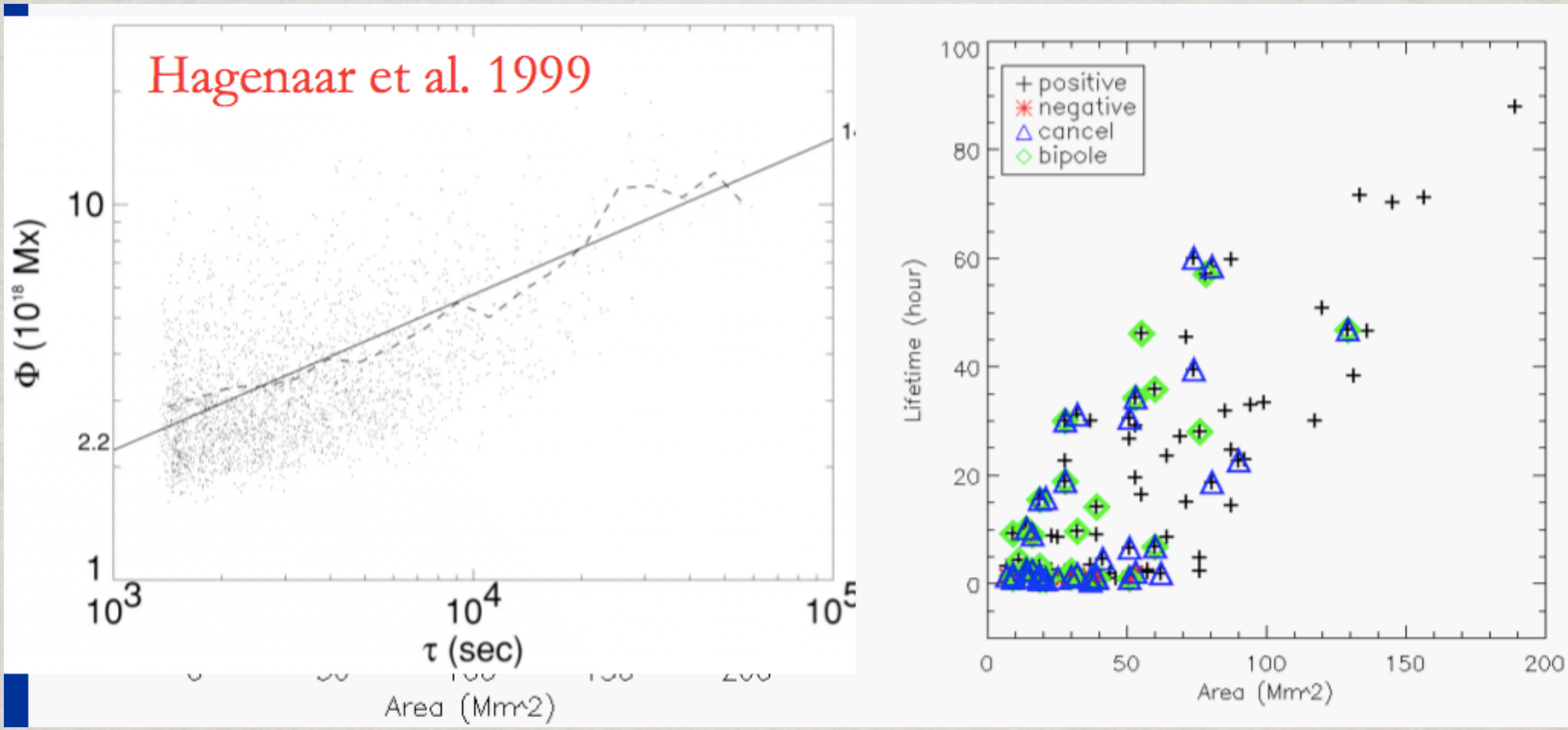


Full vector inverted field strength, reprojected



Stokes-V (line-of-sight) field strength, reprojected

MAGNETIC STRUCTURE

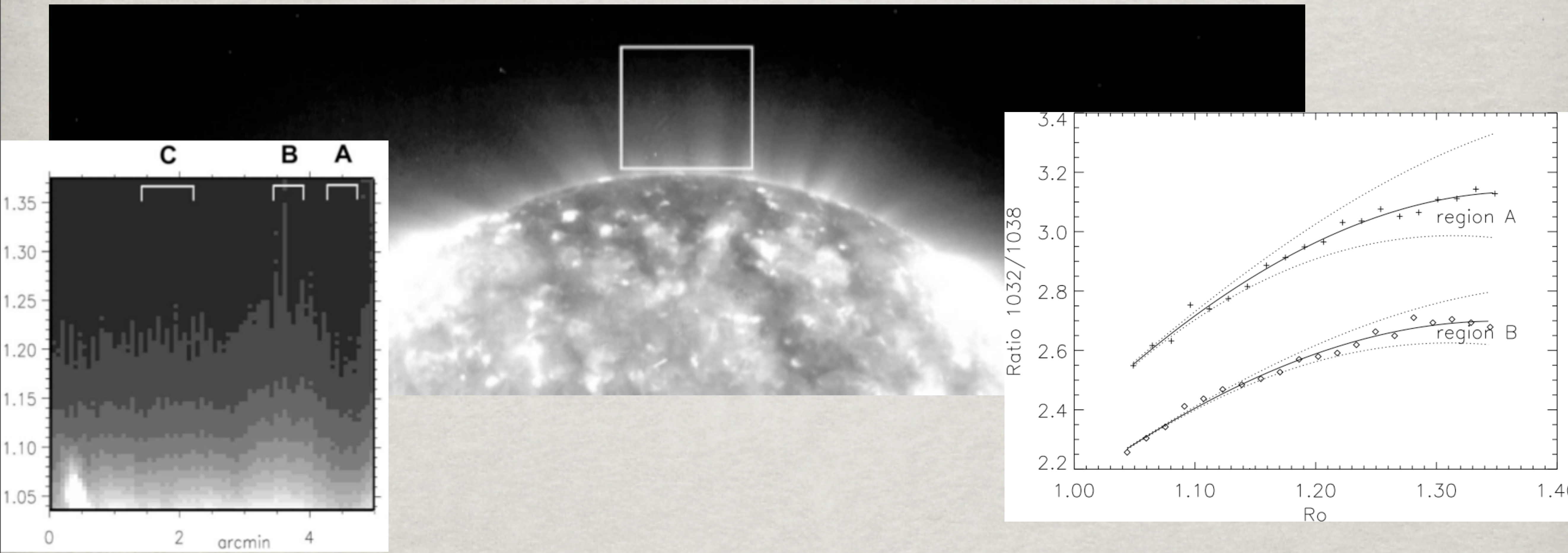


Benevolenskaya et al. 2007: "Polar elements have a tendency to be present for 1-2 days";

Liu et al. 2008: lifetime distribution is asymmetric: forward elements ~1 day; opposing elements 1-2 hours(!)

DeForest et al. 2007: don't trust lifetimes much! (but they are useful as a comparative measure within a particular study)

Plume morphology

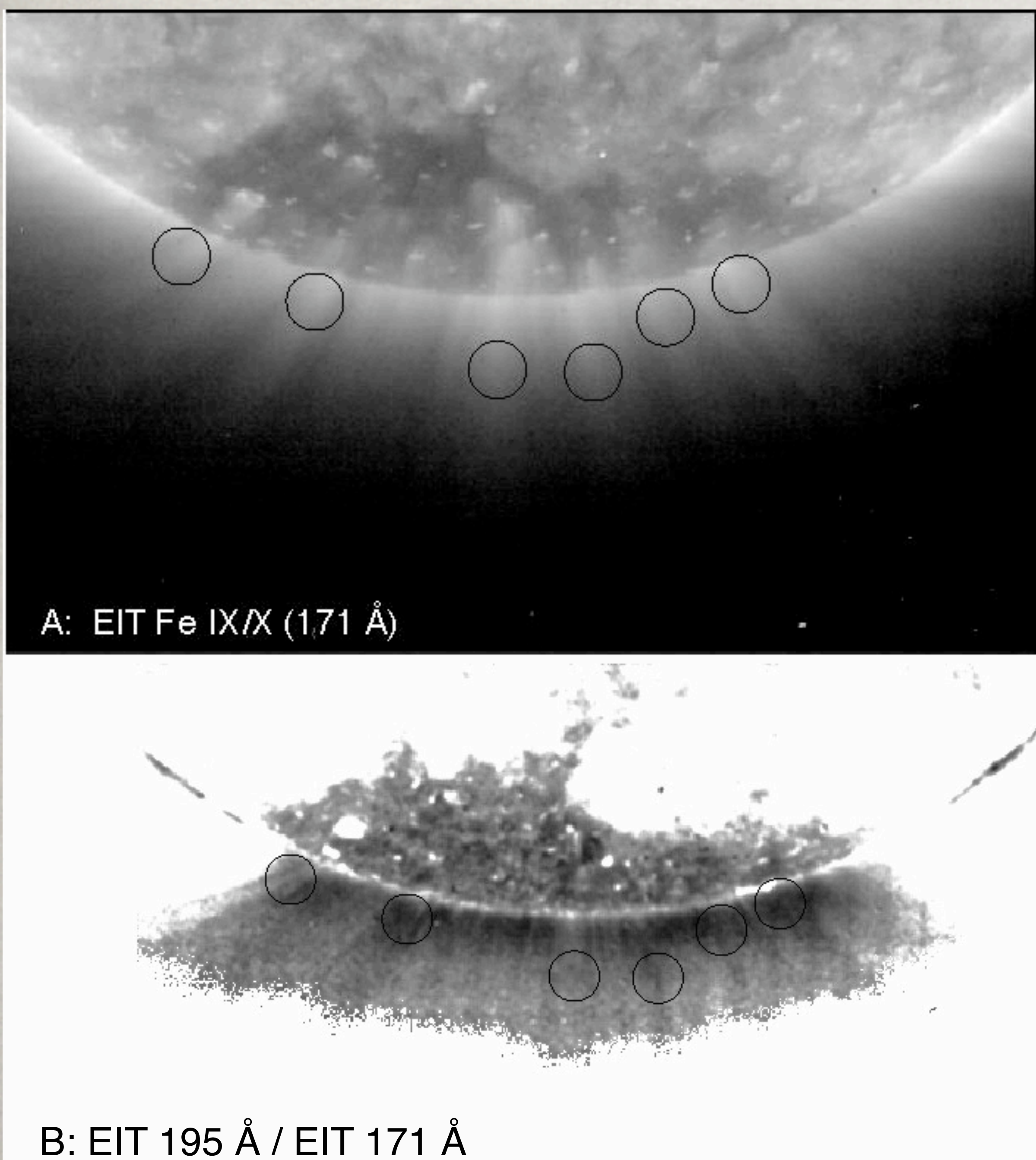


- Gabriel et al. 2003: Doppler dimming study:

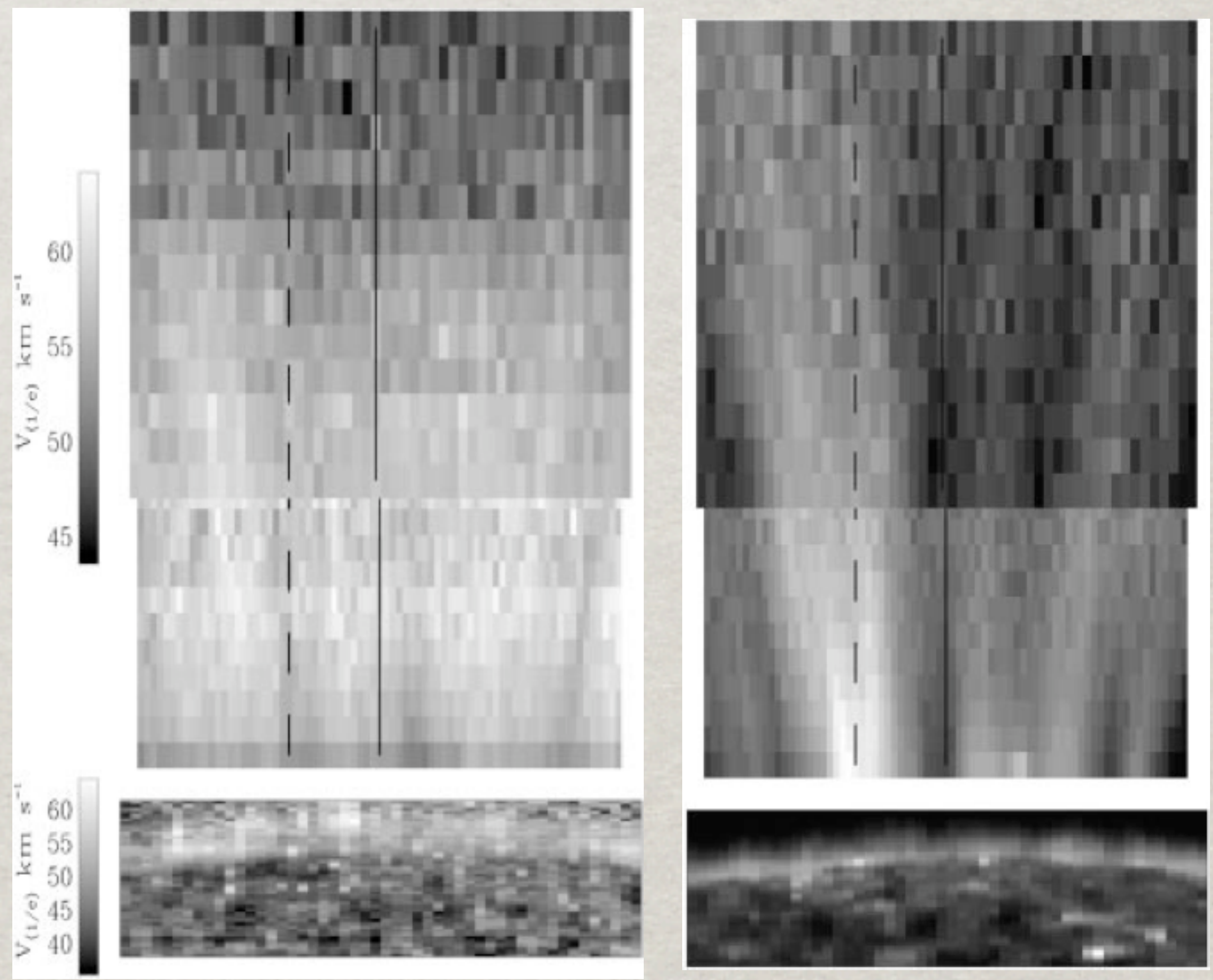
"Plume velocities are in excess of 60 km/s … throughout this height region. …Plume material makes a substantial contribution to the total line of sight, favoring … a 'curtain' model for plume … Approximately half of the fast solar wind at 1.1 Rs arises from plumes."

Temperature structure

Cooler in ionization
(e.g. DeForest et al. 1997)

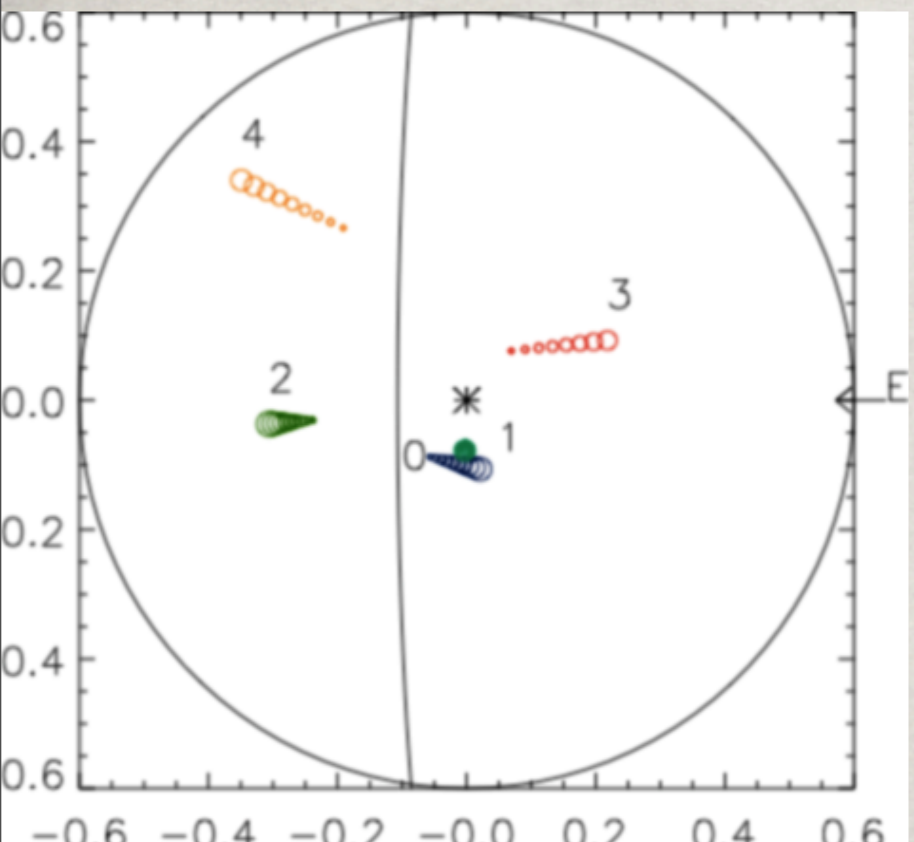


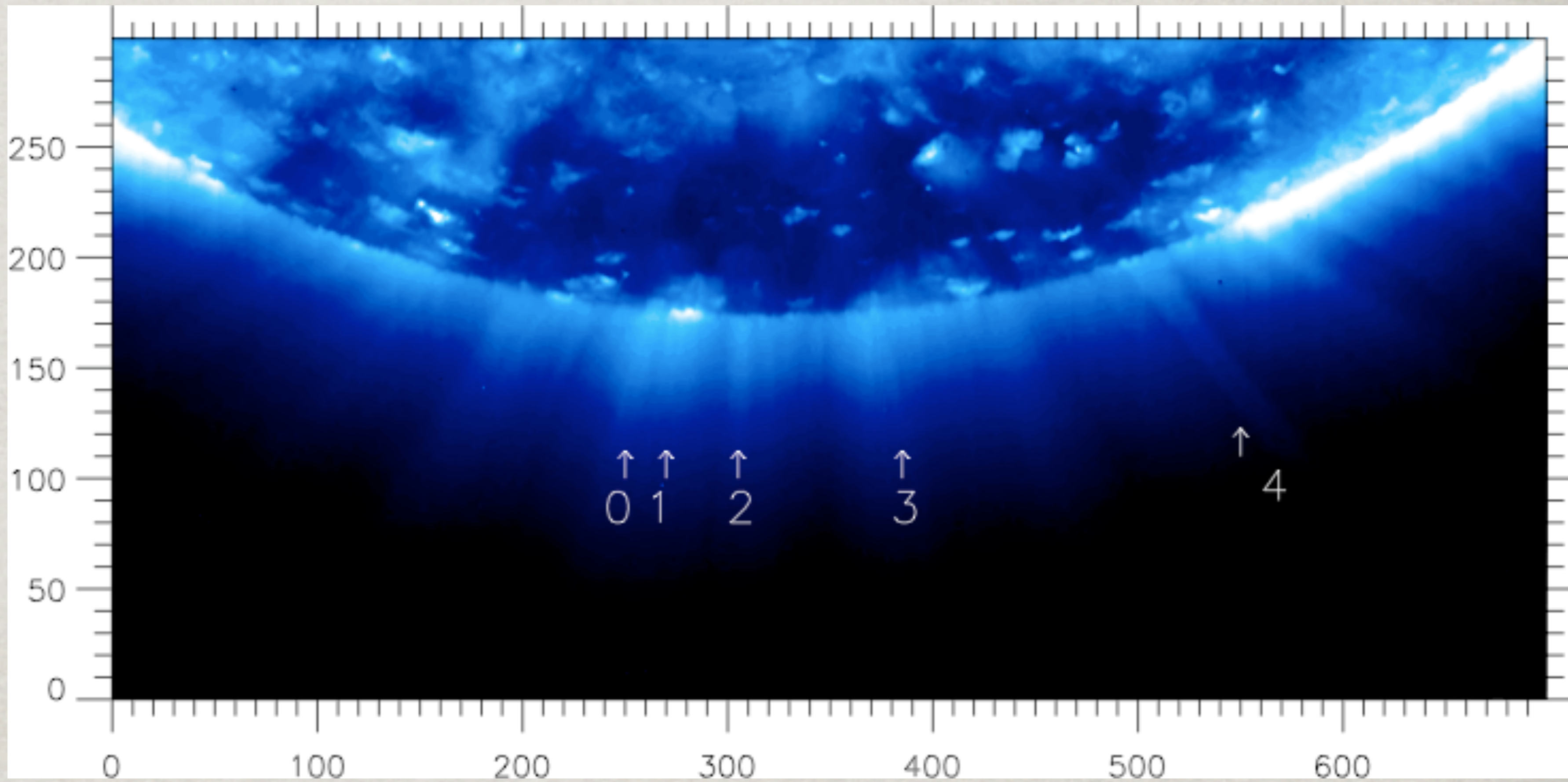
Cooler in Doppler width
(Banerjee et al. 1999, Hassler et al. 1997)



SUMER O VI 1032 Å width SUMER O VI 1032 Å int.

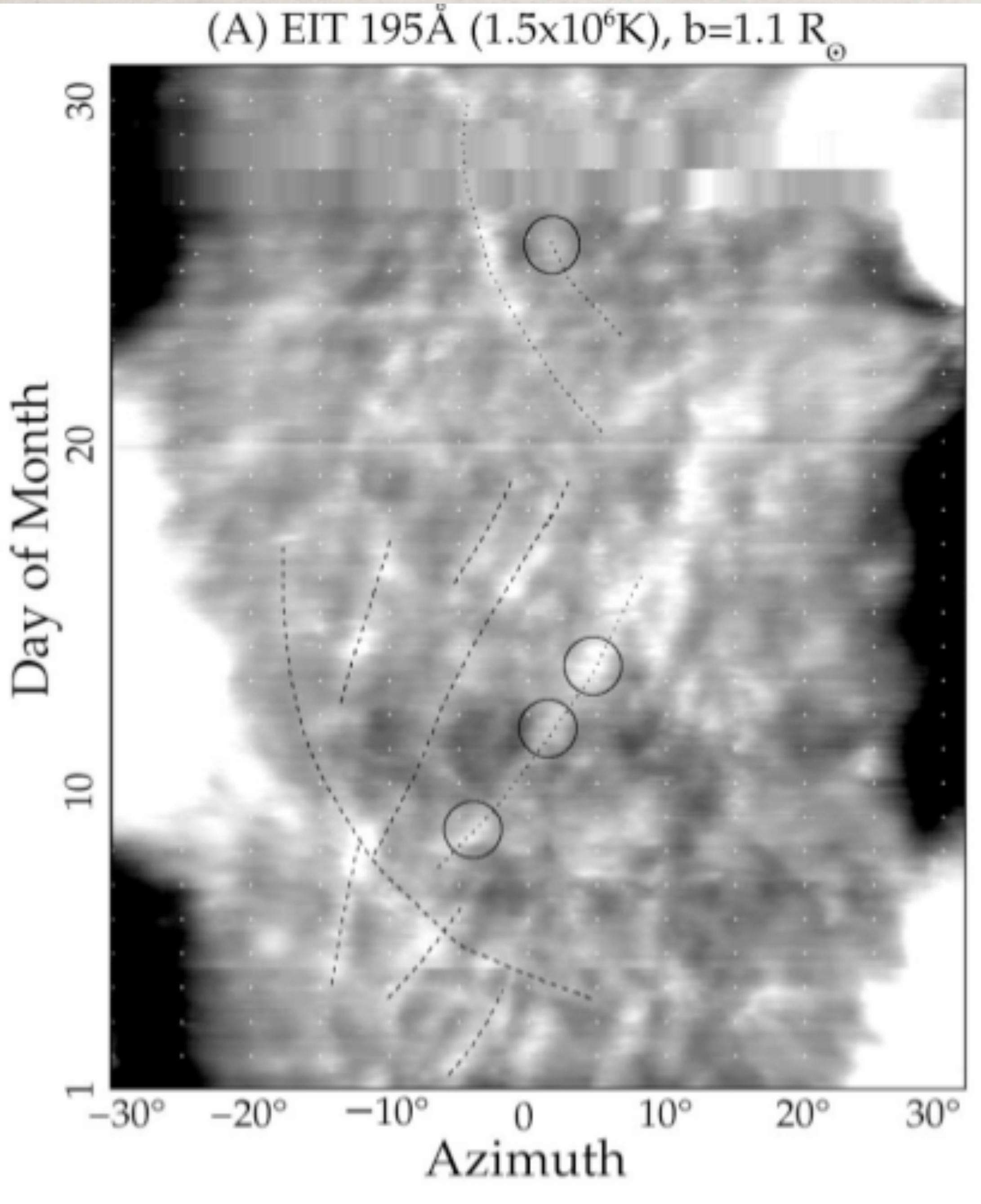
Plume morphology





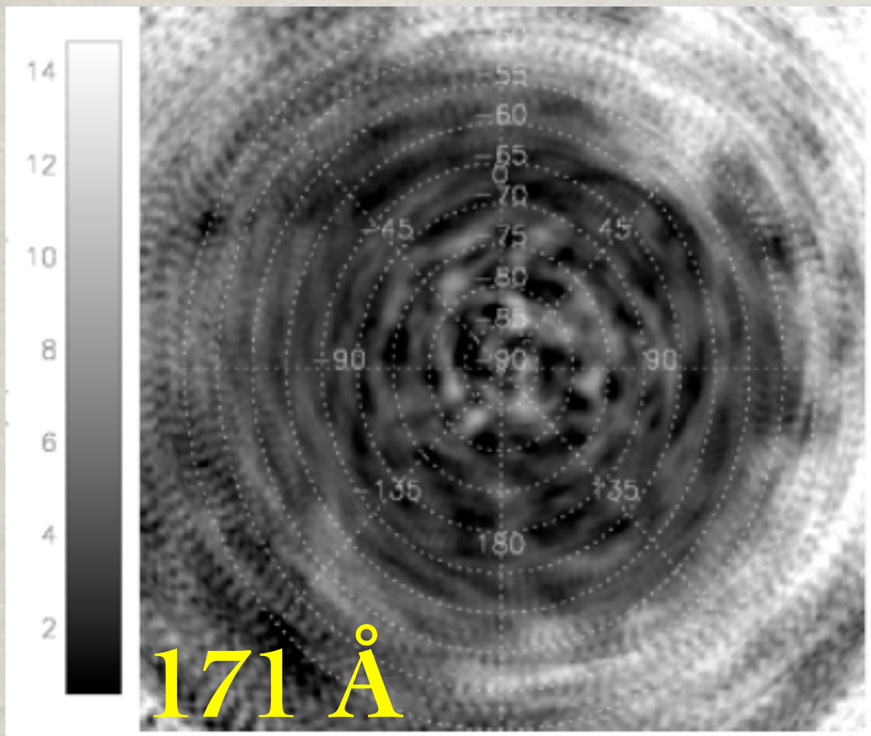
Curdt et al. 2008 (3-D morphology from STEREO):
"These observations ... favour the view that the cross-sections of plumes are restricted along the LOS direction, and thus the total area occupied by all plumes is small compared to the size of the CH."

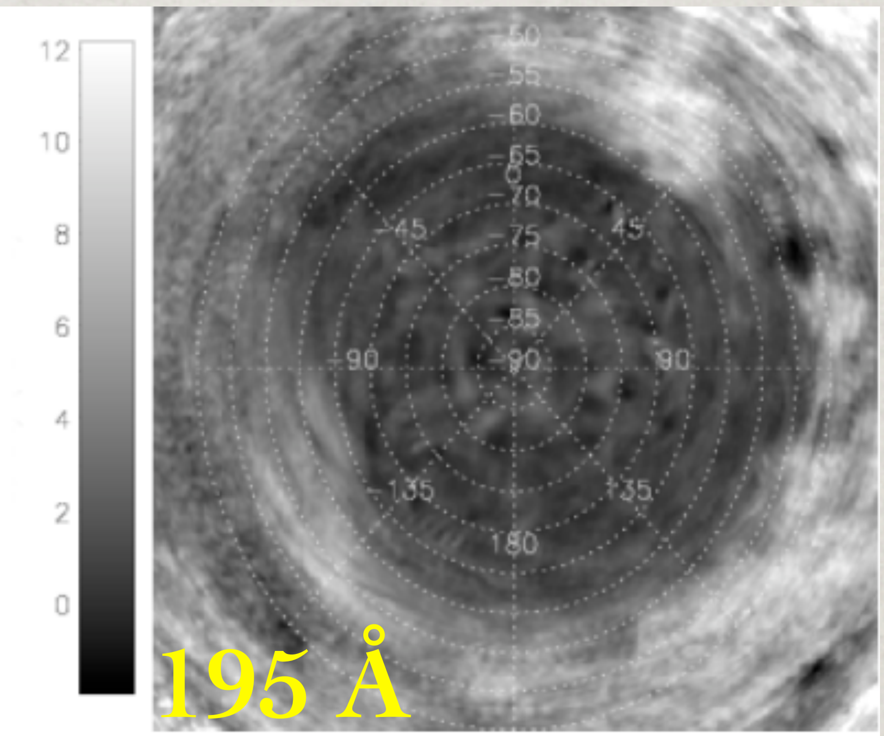
Plume lifetime

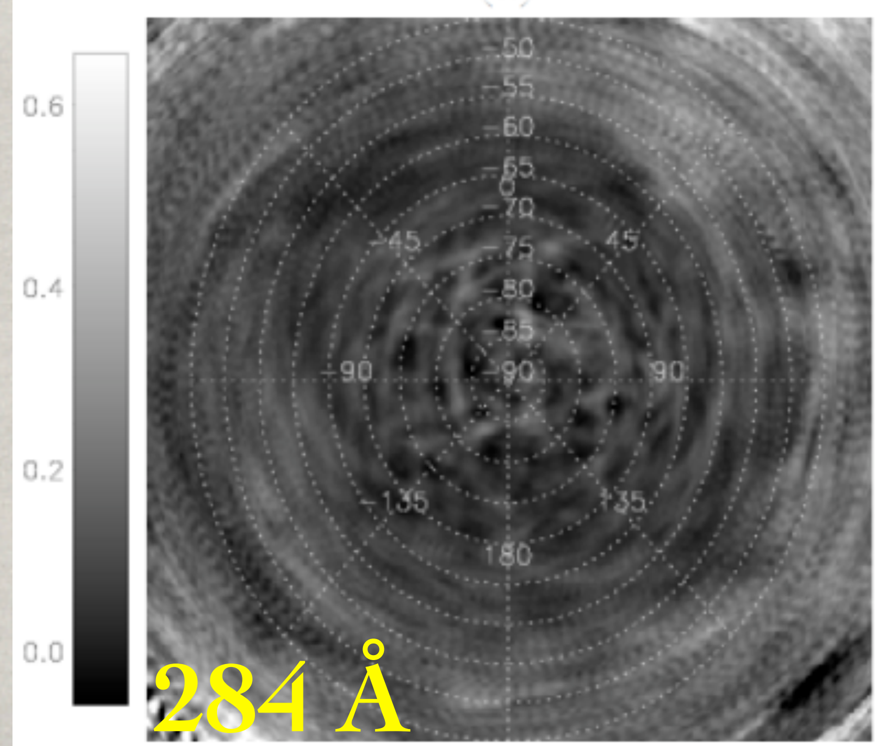


- ~1 day, recurring for weeks (from flux being driven into the base?) (DeForest, Lamy, & Llebaria 2001)
- Cooling time is shorter than lifetime -- quasi-steady heat

Plume morphology

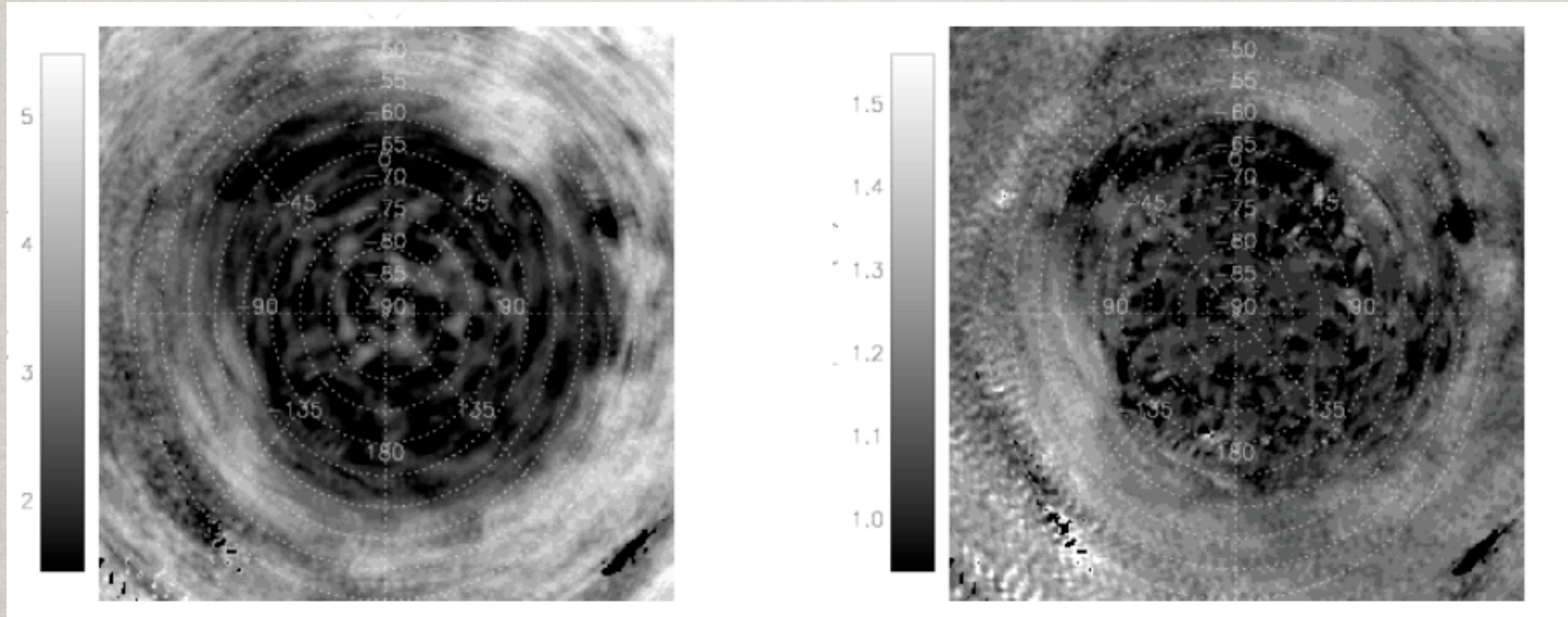






- N. Barbey 2008 (Ph.D. Thesis): Time-dependent rotational tomography using 3 views plus evolution: plumes appear to exist both as localized bright tubes and as "curtains". (This could be an artifact of time dependence; further work is needed).

Plume morphology



Density (x10^8/cm^3)

"Temperature" (x10^{6}K)

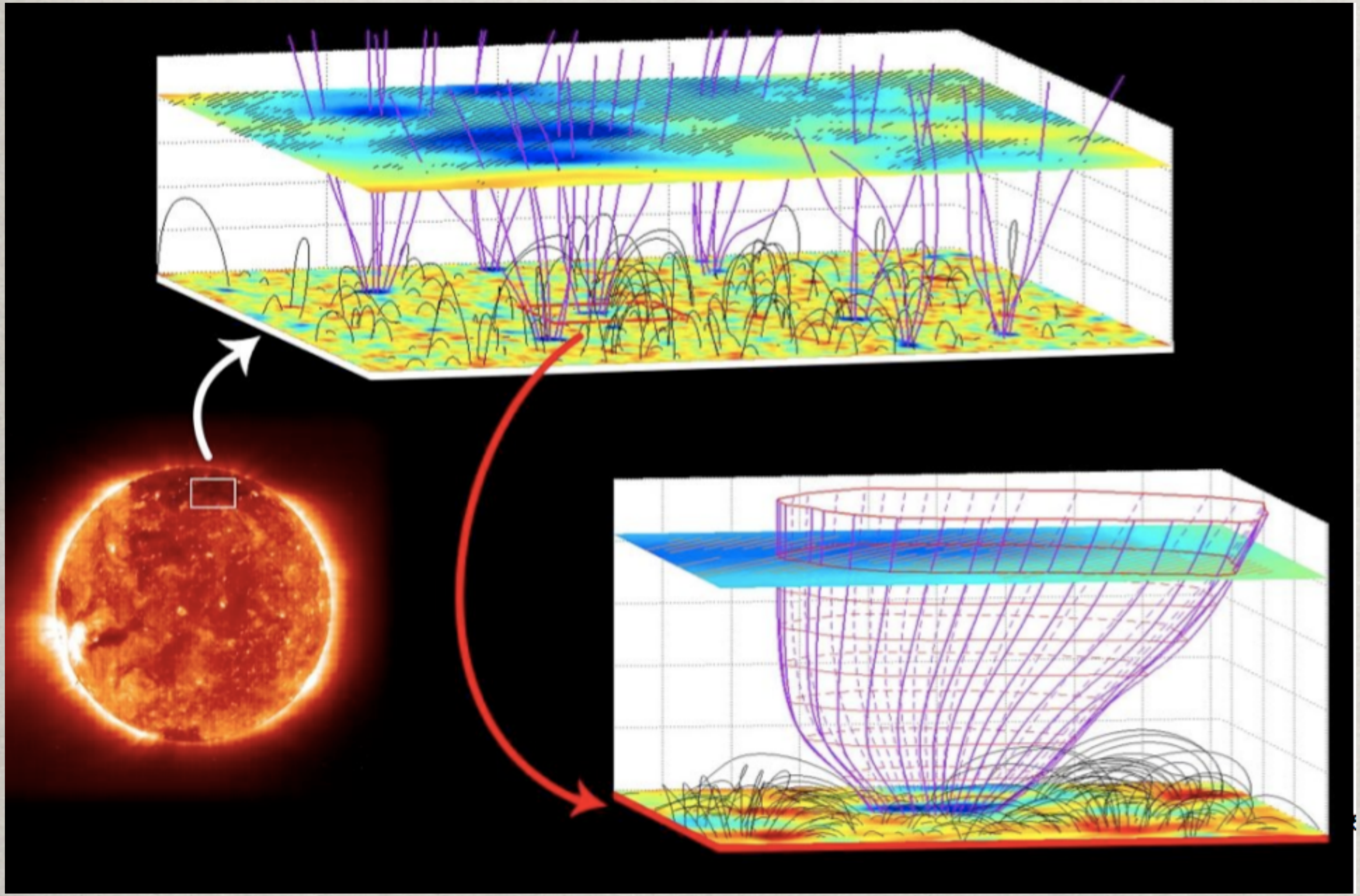
Temperature/density-inverted tomographic cuts

- N. Barbey 2008 (Ph.D. Thesis)

Plume formation

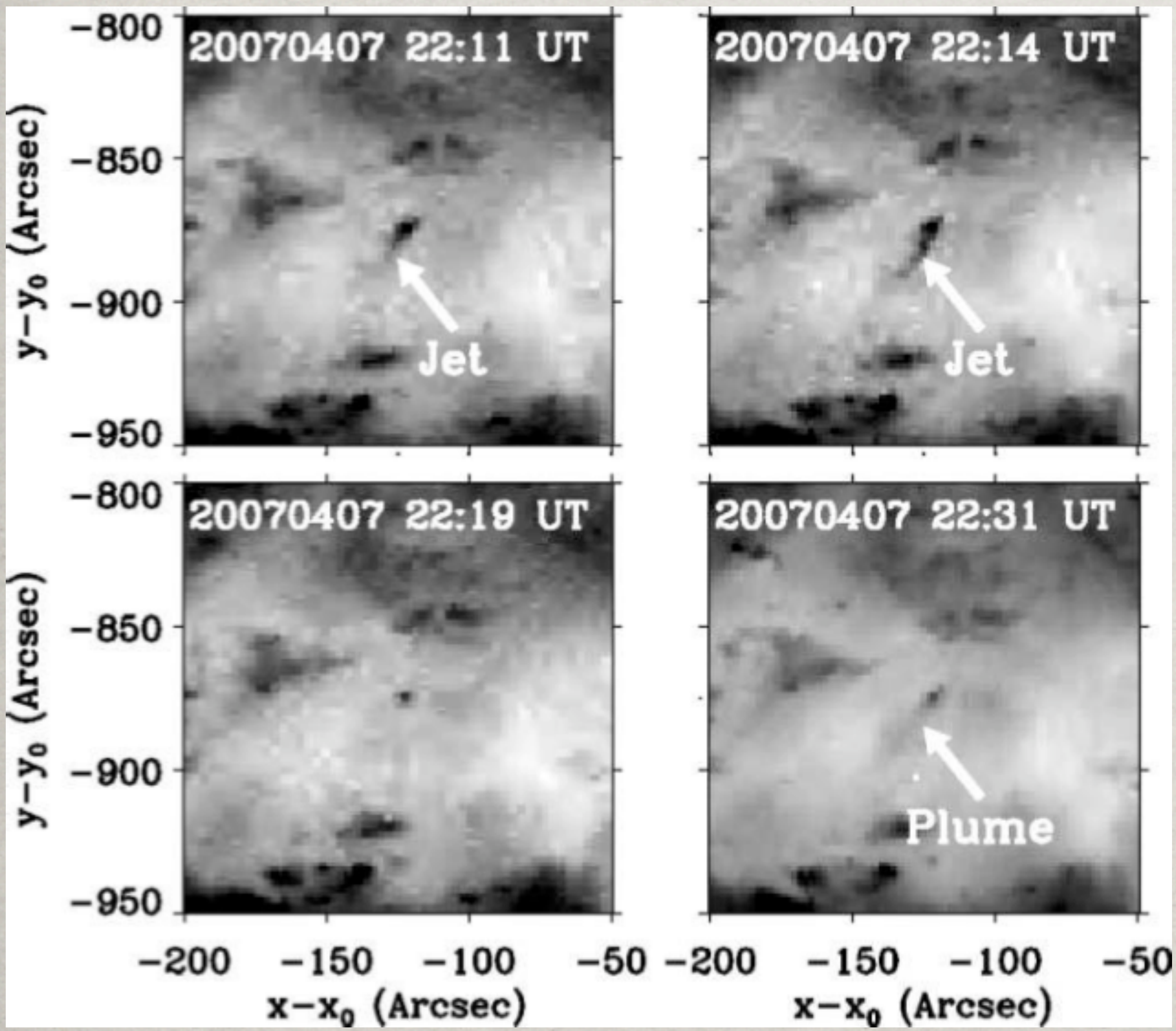
- Jet-like formation (e.g. Wang & Sheeley 1994; 1995)
- Mixed-polarity flux interaction (Wang et al. 1997; DeForest 1997)
- Aftermath of jets (Raouafi et al. 2008)
- Pseudostreamers (Wang & sheeley 2007)
- Wave heating (from CoMP; ?

Plume Formation



Tu et al. 2005: "The transition region in CHs is full of magnetic loops of different sizes ... Supergranular plasma convection ... transfers magnetic energy that is stored in the loops. They ... move to a funnel...and undergo reconnection with existing fields. ... parts of the plasma contained in reconnecting loops is brought into the corona."

Plume Formation



- Raouafi et al. 2008:

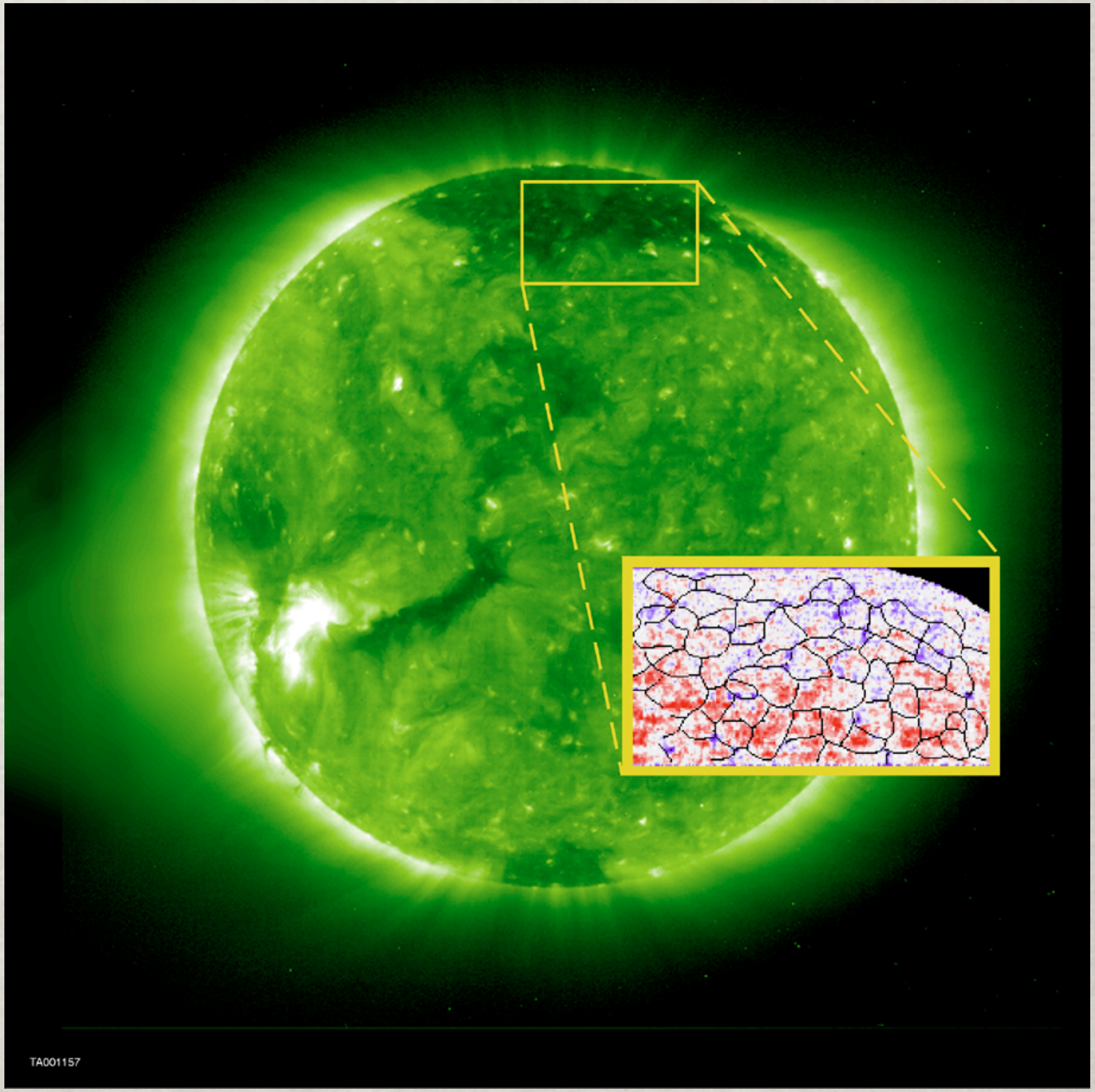
  -“Jet eruption seems to be the result of ... emerging flux that reconnects ... with the ambient photospheric field.”

  -“Coronal plume haze is observed following jet events.”

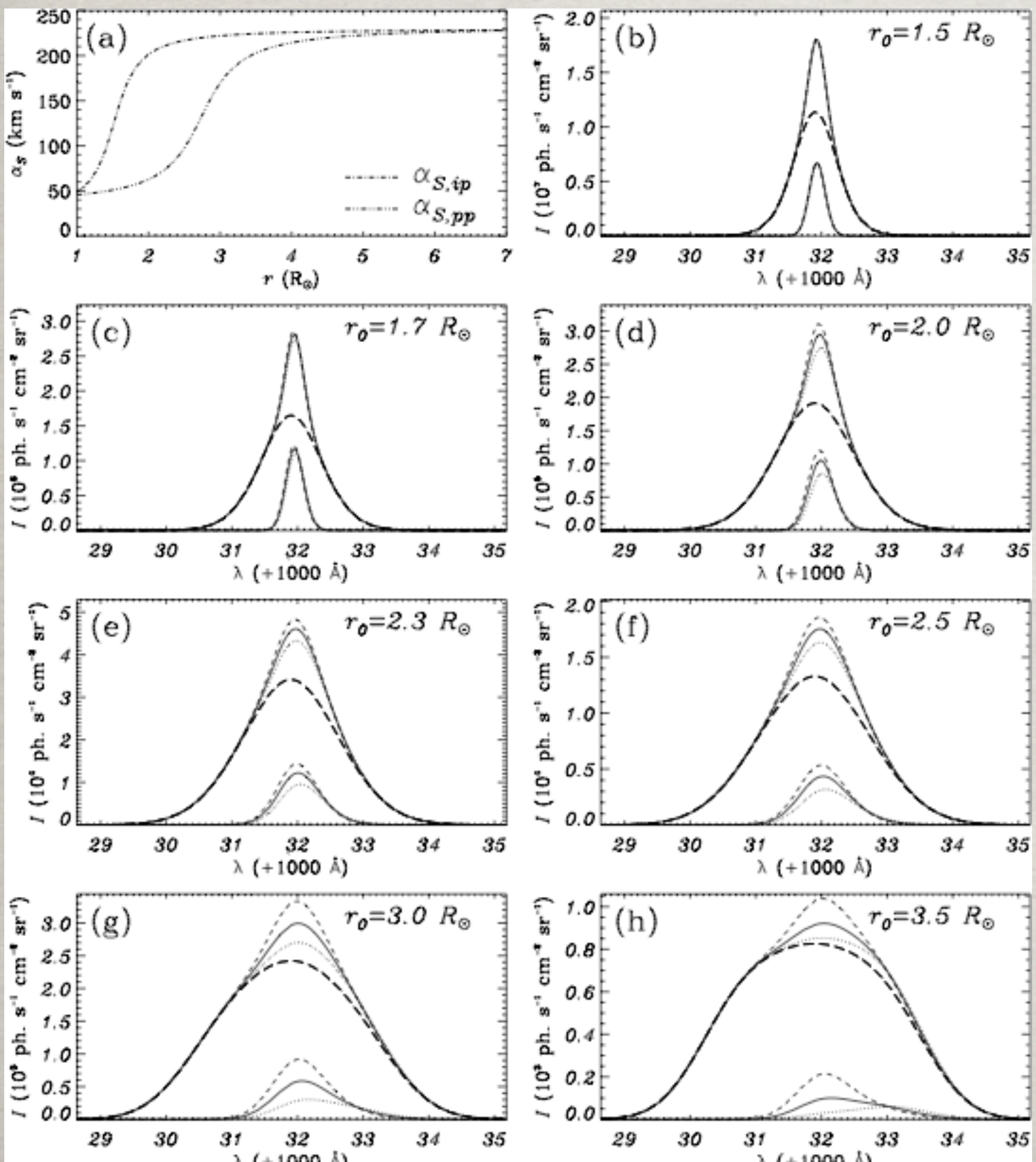
  - “The continuous emergence of magnetic flux at a slow rate ... might ultimately create a sizable bundle of newly opened flux, allowing in turn a signifian plume of escaping plasma to develop.”

Plumes and Wind

- "Interplumes are the primary source of the high speed solar wind" (Wang 1994)
- Wind arises from network intersections (Hassler et al. 1999)
- Plumes do not show signs of outflow (at low altitudes) (Wilhelm et al. 2000)
- Problems: If plumes do not source flow, how do they get so tall? If the flow is different from the interplumes, why do they not break up in the outer corona? (DeForest, Plunkett, & Andrews 2001)



Plumes and Wind



- Raouafi et al. 2007: "...this model suggests that the plume plasma remains much slower and cooler than interplume material up to ~2.0 Rs. Above 2.0 Rs these parameters experience a rapid rise toward interplume values, reached by ~3.0 Rs. ... [this is] probably the result of interaction with the ... interplume material."

- Density contrasts have been rising: spectral contamination (Del Zanna, Bromage, & Mason 2003); instrumental scattering (DeForest, Martens, & Wills-Davey 2008)

- Result: wind in plumes is again an open question...?

Waves in the wind

- Wang 1994: an extended heating source (such as Alfvén waves) is needed to drive solar wind out of plumes
- Kohl et al. 1997: ion-cyclotron resonant waves (~100Hz) are likely (indirect detection)
- DeForest & Gurman 1998: detection of 1mHz slow waves in plumes
- Tomczyk et al. 2008: detection of Alfvén waves in the corona (CoMP)
- De Pontieu et al. 2008: detection of Alfvén waves in the transition region, sufficient to drive the solar wind

So, er, what's different?

- Better understanding of morphology (curtain/tube debate *may* be resolved)
- Better magnetic resolution (from Hinode): can drive more sophisticated models
- Recent wave results from Hinode and from CoMP: the missing energy to drive wind?
- More sophisticated models of onset (e.g. Tu et al. 2005)
- Better understanding of the mass flux out of the plume (plumes appear to source at least enough wind to merge smoothly with the interplume background)
- Beginnings of a systematic data-driven onset model (jets/ reconnection)

"The more things change…" What is still needed?

- Plumes' density and outflow profile are still not well characterized in the low to mid corona (PSF effects in imagers; broadening: temperature vs. transverse motion vs. projected outflow)
- How much of the solar wind is sourced by plumes? (depends on the flow profile and relative density)
- Better understanding of the magnetic structure of coronal holes - a long-ish vector study and/or a more complete model of how holes' surface field evolves (e.g. is the observed emergence imbalance explainable solely by the flux imbalance?)
- Wind (which I'll leave to Velli)
- More - come to the Session B talks…