

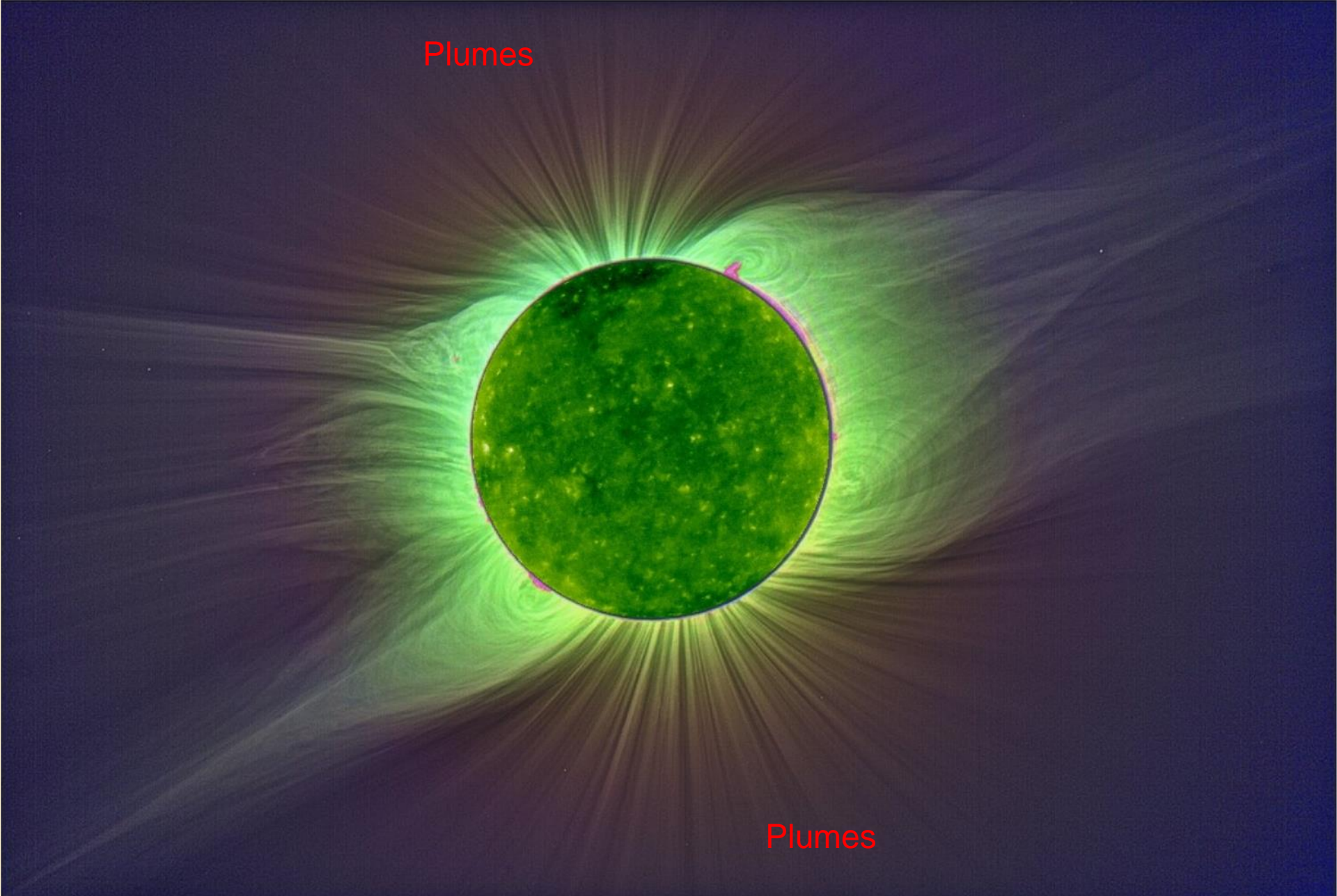
Do we understand polar coronal plumes of the Sun?

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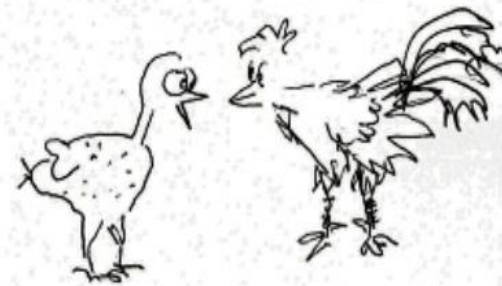
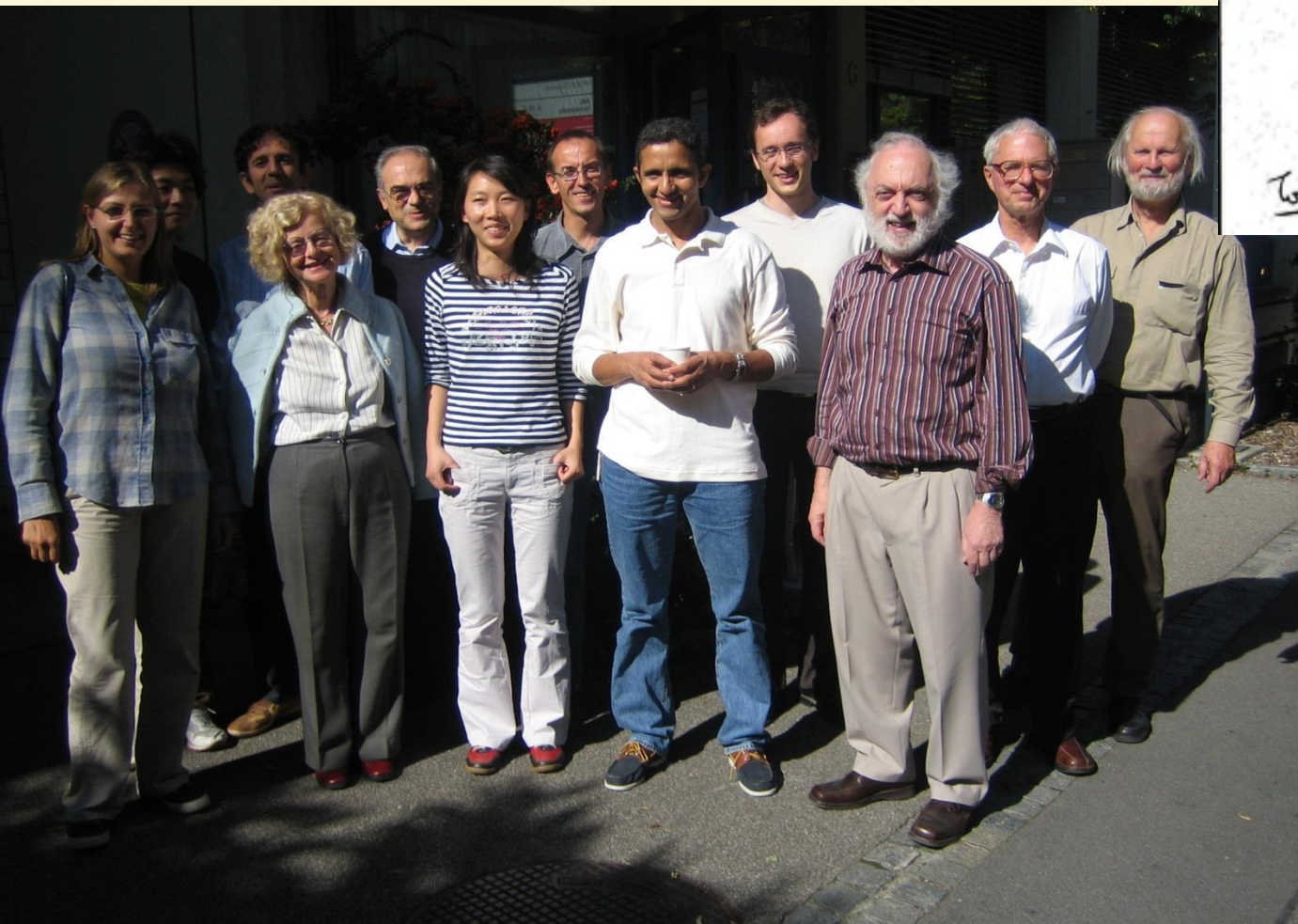
**Atomic physics, plasma spectroscopy, and solar physics from space:
Celebrating the achievements of Alan Gabriel**

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Total eclipse on 1 August 2008 observed from Mongolia (Pasachoff et al. 2009).
SOHO/EIT image in the 19.5 nm band inserted into the eclipsed solar disk.

The members of the ISSI Plume Study Team
in Bern October 2007
(without F. Auchère, W.H. Matthaeus, Y.-M. Wang)
see Ref. [6]



ALL THIS PEOPLE TALKING
ABOUT PLUMES but -
I AM A BIT SCEPTICAL!

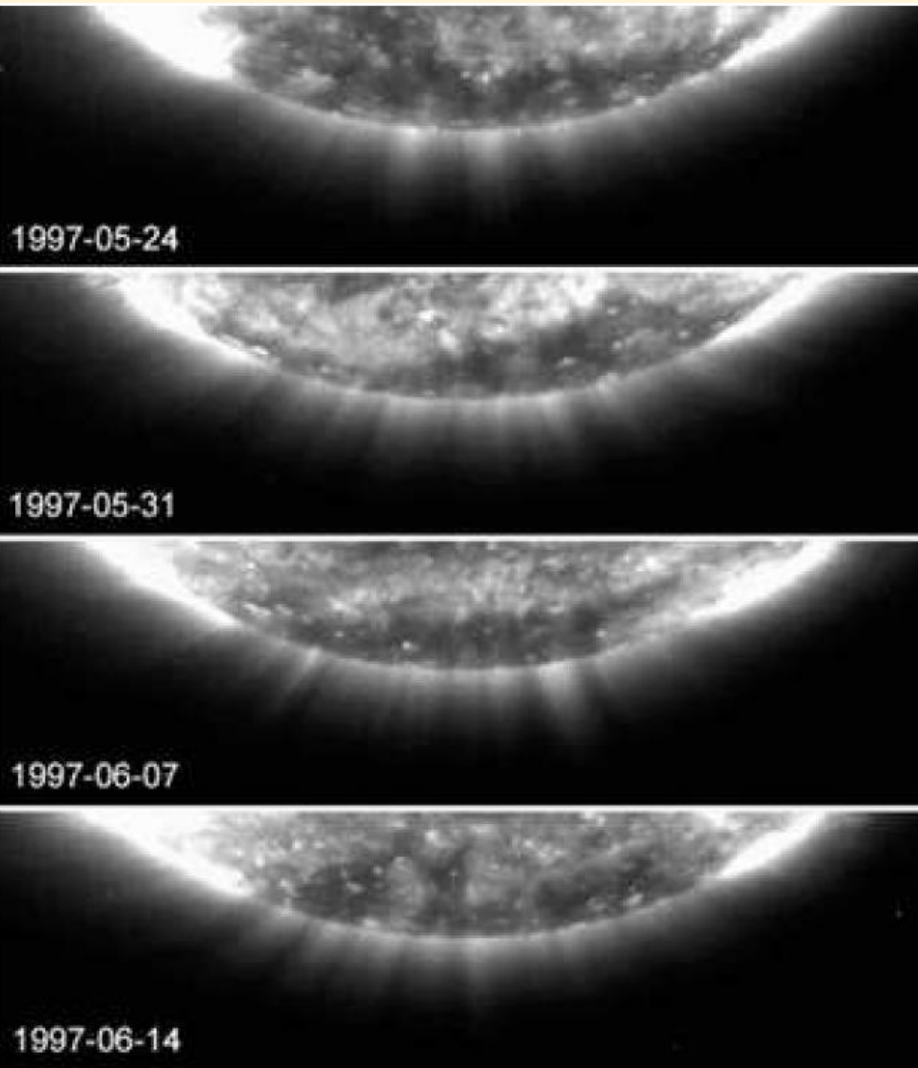
Llebaria

Antoine Llebaria's
definition of plumes

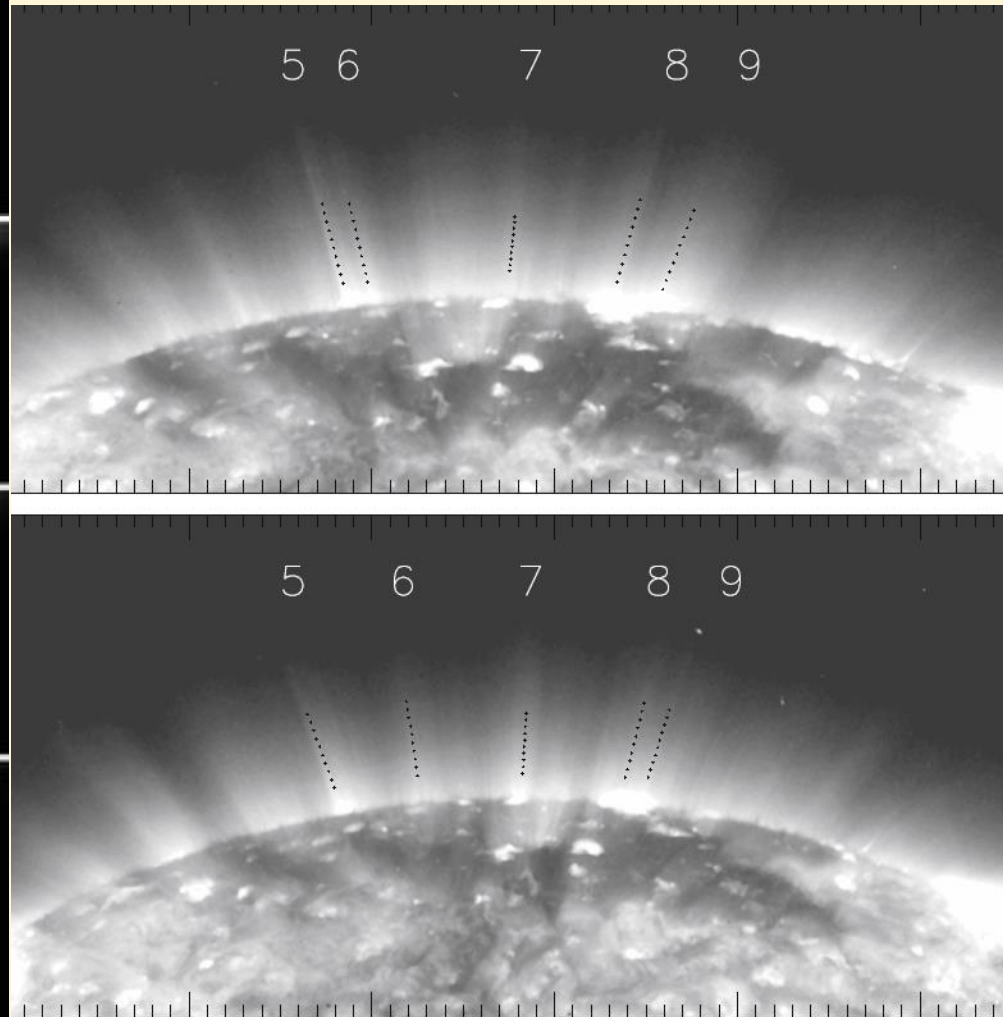
Some Agreed Plume Characteristics

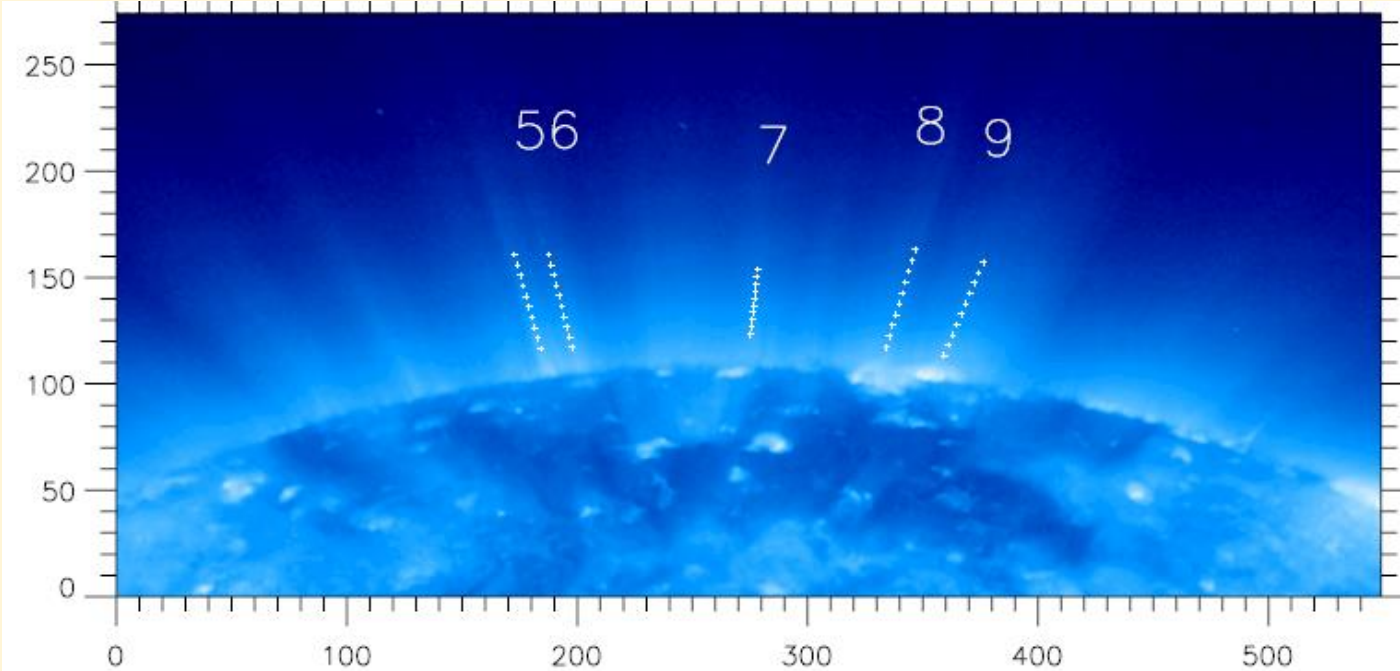
- Polar plumes delineate magnetic field lines of the minimum corona in coronal holes.
- They expand super-radially—fast below 30 Mm above the photosphere.
- Plumes result from plasma density enhancements.
- The electron density ratio between plumes and inter-plume regions (IPR) is between three and seven in the low corona and decreases at greater heights.
- The electron temperature in plumes is $T_e \leq 1$ MK. In IPRs it is higher by ≈ 0.2 MK with a tendency of even higher values at greater heights.
- The effective ion temperatures in plumes are much higher than the electron temperatures, but lower than in IPRs.
- With stereoscopic observations, 3D reconstructions of **beam plumes** could be achieved. They are, in many cases, related to coronal bright points.
- The solar wind outflow velocity is generally higher in IPRs than in plumes. The filling factor of plumes in coronal holes is ≤ 0.1 .
- Plumes and IPRs have different abundance compositions.

Four orthogonal views of a south polar coronal hole. Most of the plumes appear to originate from behind the limb. This is not compatible with **beam plumes** as the only contributors. Gabriel et al. 2009

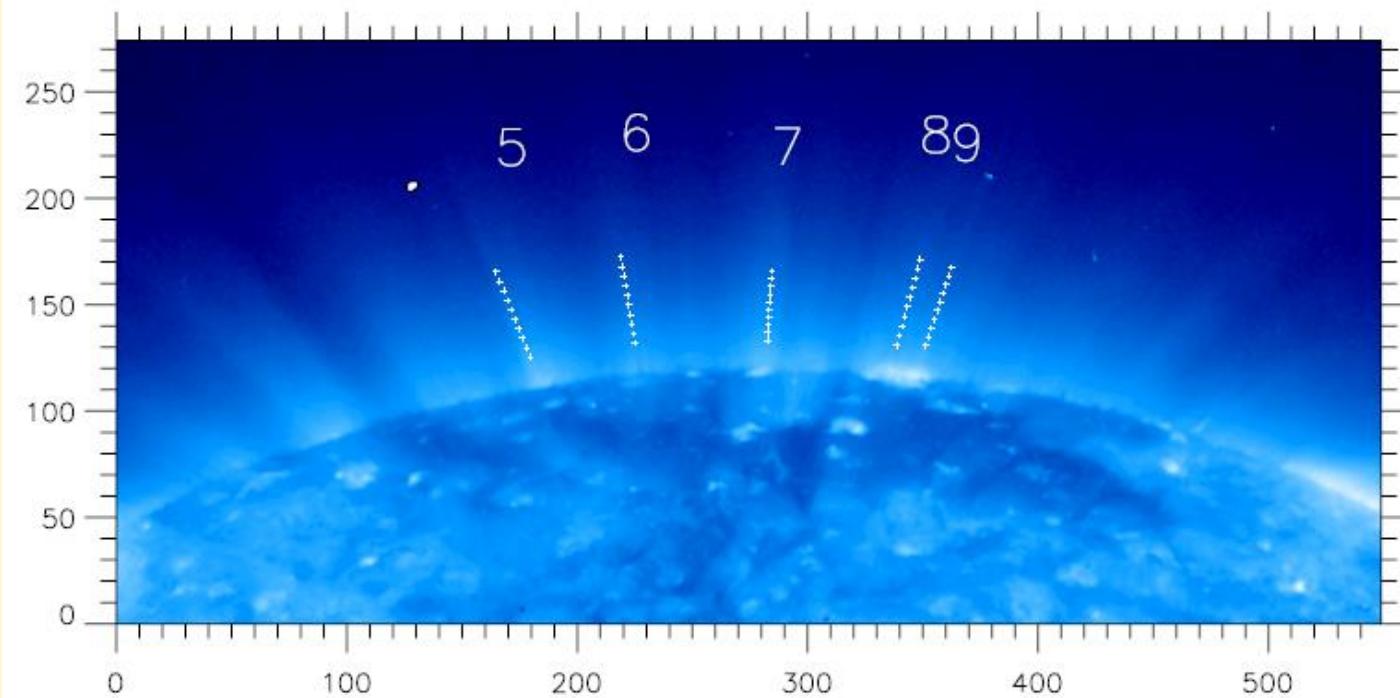


STEREO A and B observations on 1 June 2007 give the same impression. Only **beam plumes** can be traced down to the near-side of the hole. Wilhelm et al. 2011

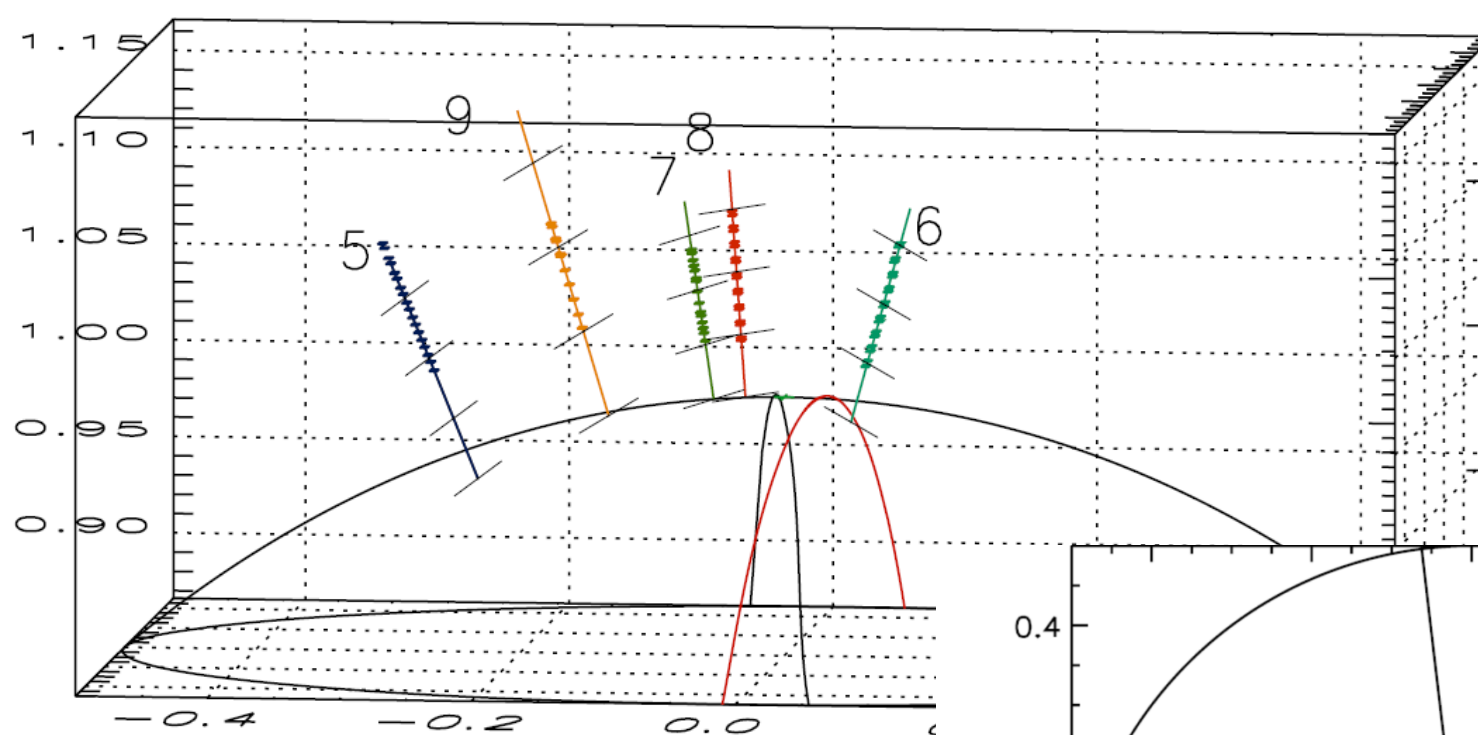




A coloured version of the STEREO observations on 1 June 2007. The **beam plumes** which could be identified in both the EUVI A and B images are numbered and treated in a stereoscopic 3D reconstruction in the next viewgraph.



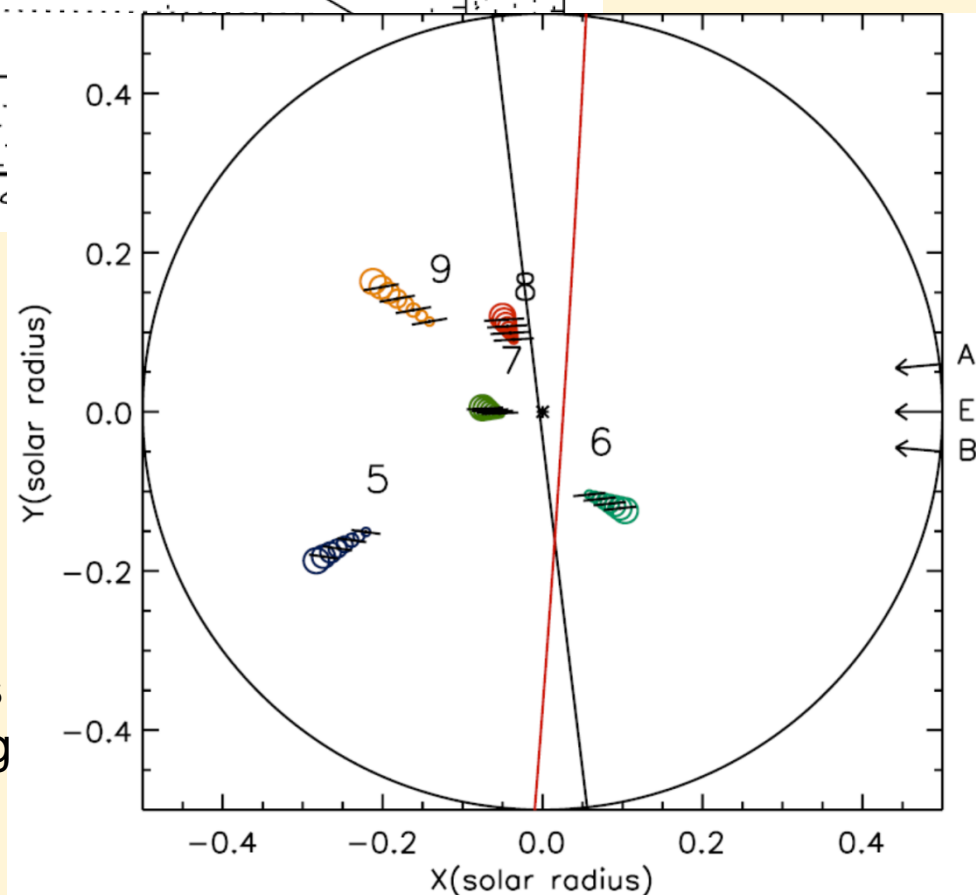
Feng et al. 2009



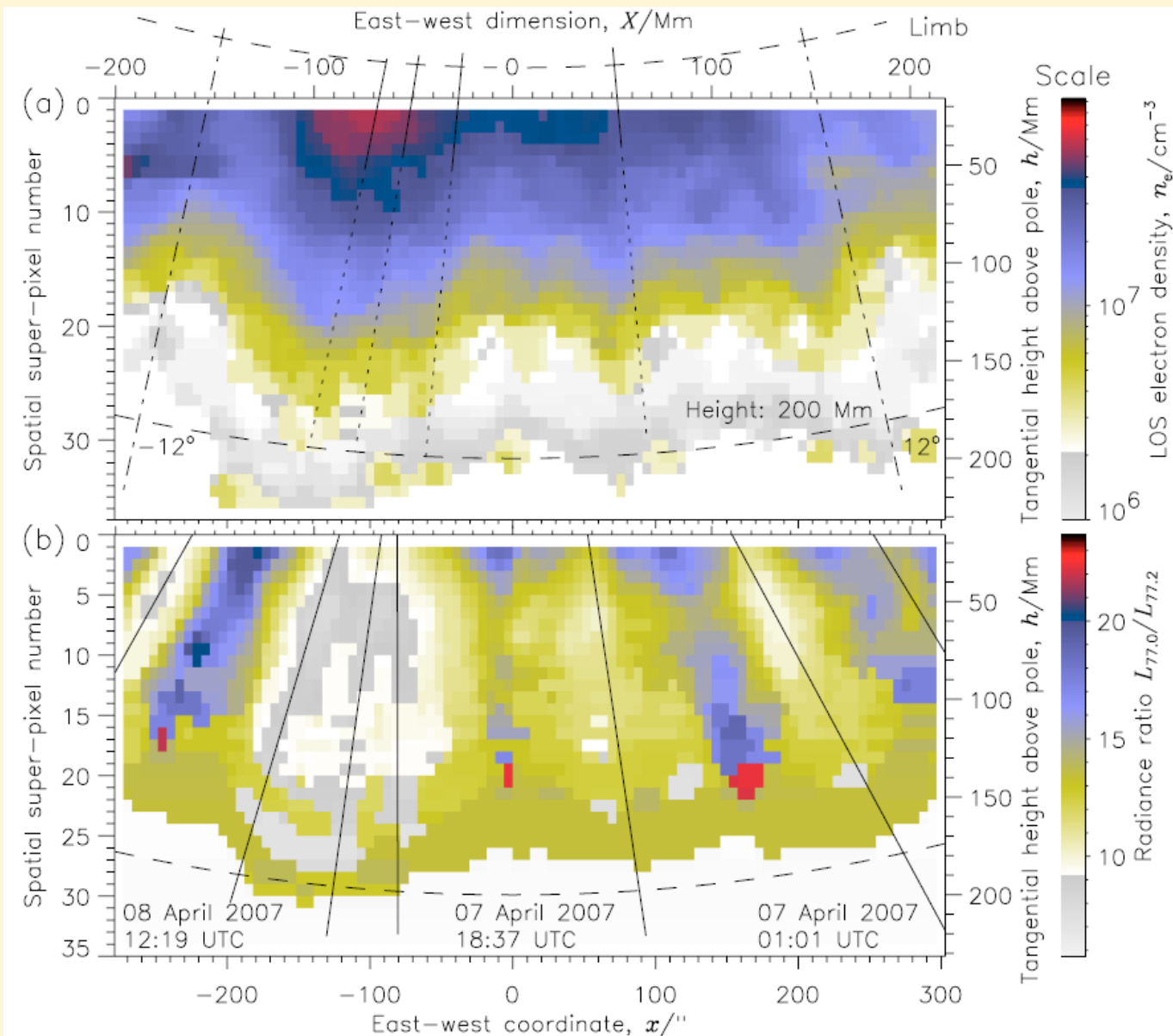
Feng et al. 2009

Side view of the north polar cap on 1 June 2007. The **beam plumes** 5 to 9 are indicated.

Projections of the reconstructed 3D plumes onto the solar equatorial plane. The viewing directions from Earth as well as from STEREO A and B are shown on the right.



Plumes and IPRs in the southern coronal hole

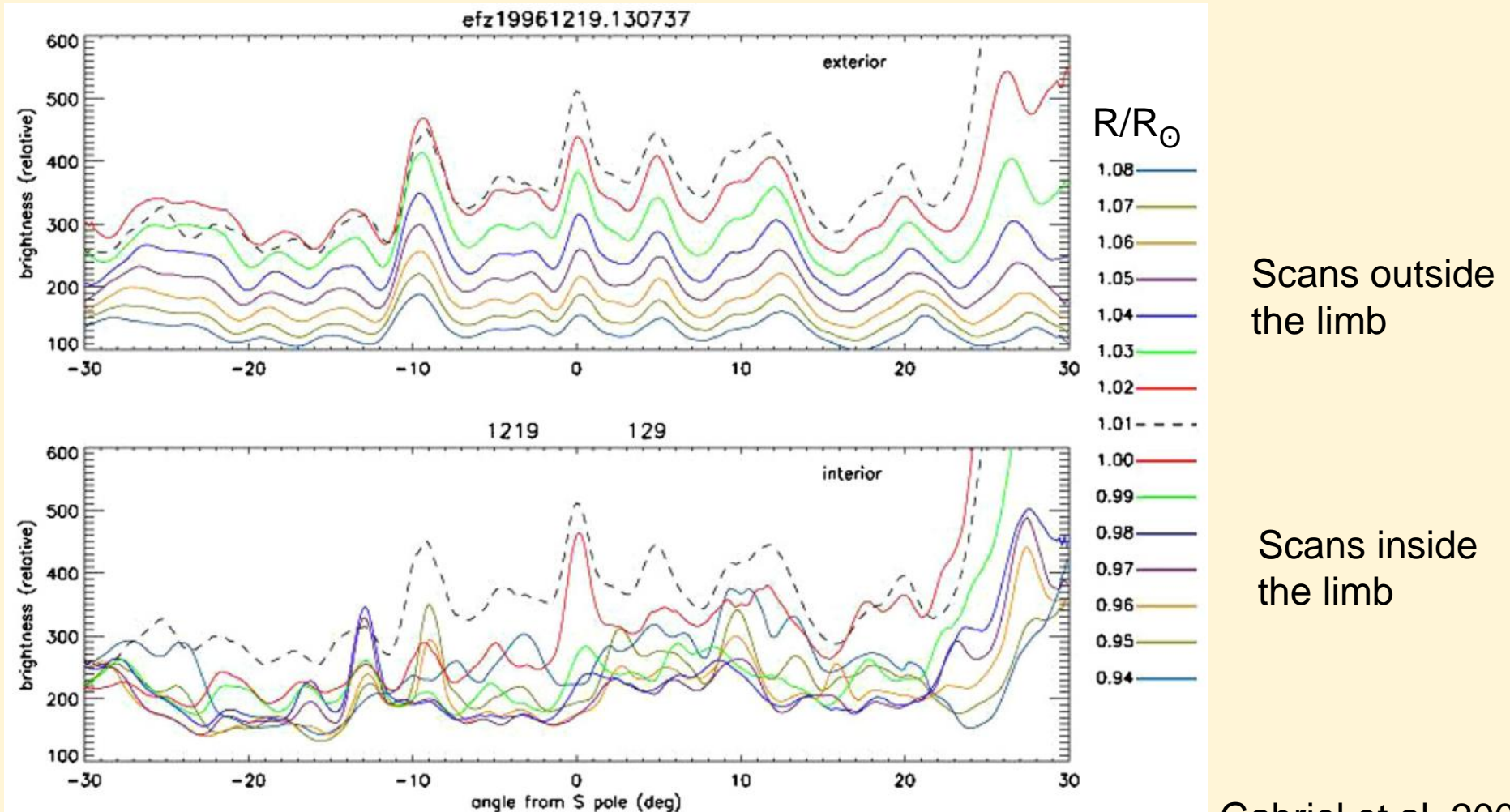


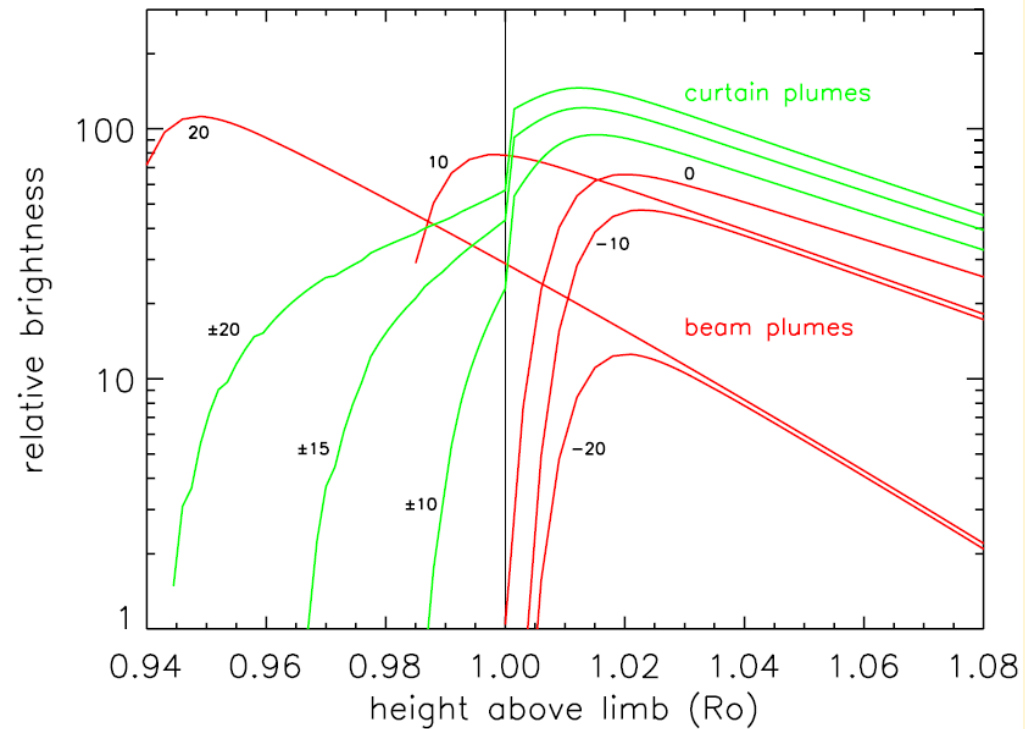
Electron density

Line ratio of a Ne VIII spectral line and a Mg VIII line. Neon is a high FIP element and magnesium a low FIP element. Plume material contains more of the low-FIP element.

Curdt et al. 2008

Limb scans of one image in a polar coronal hole observed by EIT in the 17.1 nm window on 19 December 1996. Indications of **curtain plumes**: visible only edge-on.

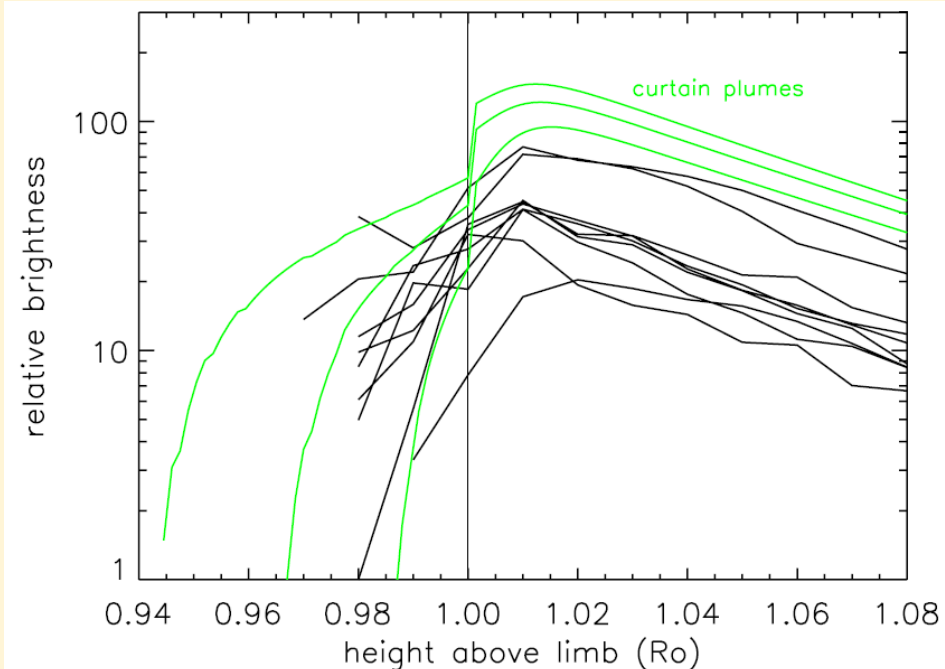
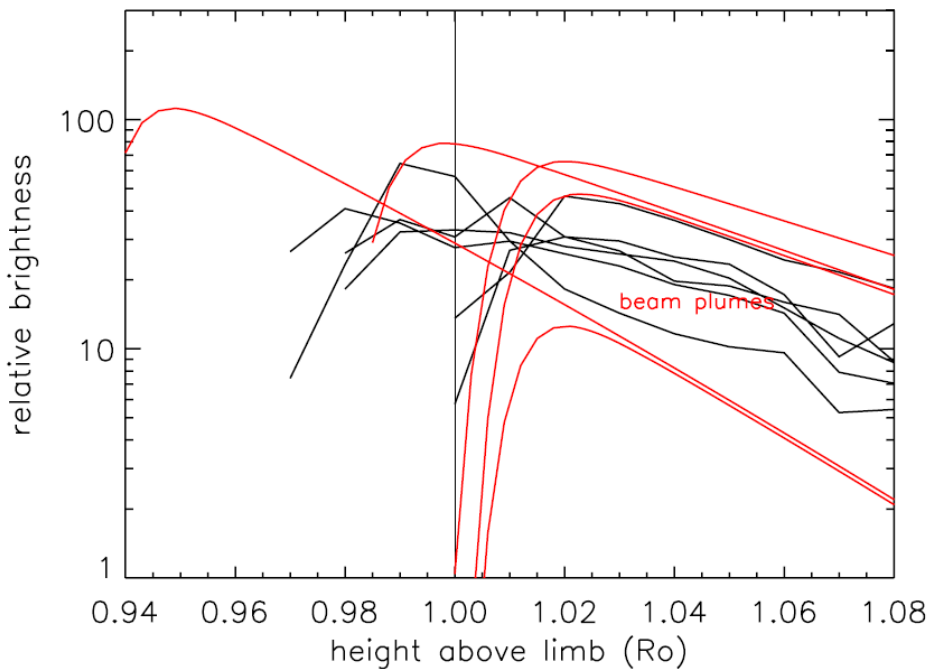




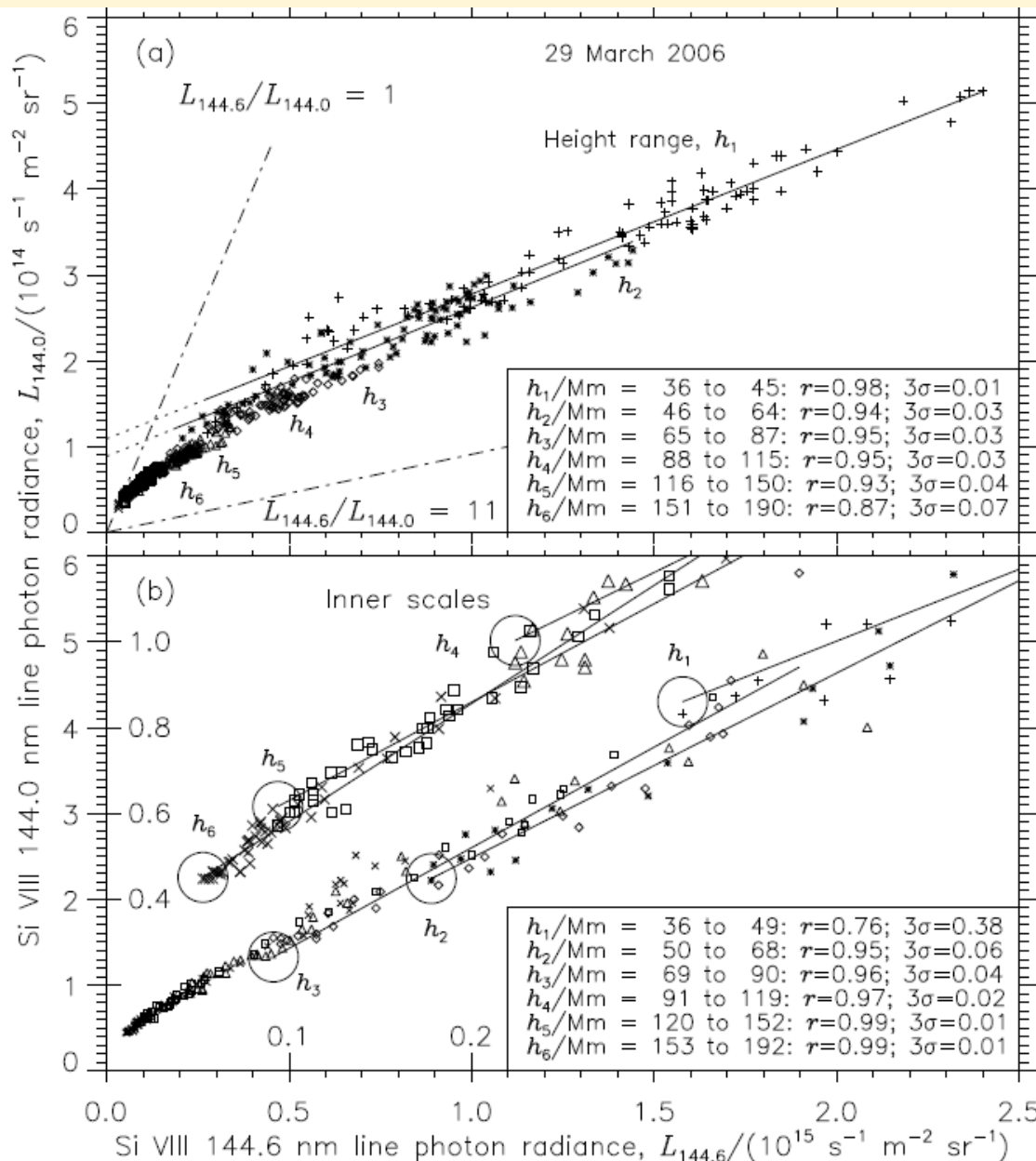
Model calculations for
plume brightness falloffs

Gabriel et al. 2009

left: Beam plumes Curtain plumes
with observations



Radiance of the Si VIII 144.0 nm line as function of the 144.6 nm radiance.
The ratio is density sensitive. Tangential scans at different heights are shown.



Wilhelm et al. 2011

All linear fits of the data points do not pass through the origin, and all data points at a given height are above certain ratios (encircled in the lower diagram). The only explanation appears to be that two density regimes are encountered along the line-of-sight directions: plumes and IPRs.

This result is not consistent with contiguous **curtain plumes**, but with **microplumes** aligned along network structures.

Gabriel et al. 2009

Classes of Plumes Structures and Open Questions

Microplumes and network plumes

- Based on EIT observations, in addition to **beam plumes**, a second class of plumes appears to exist. They are composed of small structures, called **microplumes**, with footpoints along network lanes. They are called **network plumes** and are only visible when the line of sight is directed edge-on.
This concept has been suggested by Alan Gabriel.
- It is, however, not excluded that **beam plumes** are also composed of **microplumes** in a more compact fashion.

Open questions

- Although models of plumes and their formation through magnetic reconnection and additional heating near their footpoints (cf. Wang 2012) are available, an exact description of the physical processes operating at the base and inside of plumes as well as their interaction with the solar wind is still outstanding.
- Is there any contribution of plume plasma to the fast solar-wind streams at all?
- What produces the first ionization potential (FIP) effect in plumes and inter-plume regions? Is it related to the containment time of the plume plasma?

References

- [1] W. Curdt, K. Wilhelm, L. Feng, S. Kamio: Multi-spacecraft observations of polar coronal plumes.
Astron. Astrophys. 481, L61-L64 (2008)
- [2] L. Feng, B. Inhester, S.K. Solanki, K. Wilhelm, T. Wiegelmann, B. Podlipnik, R.A. Howard, S.P. Plunkett, J.P. Wuelser, W.Q. Gan: Stereoscopic polar plume reconstructions from STEREO/SECCHI images.
Astrophys. J. 700, 292-301 (2009)
- [3] A. Gabriel, F. Bely-Dubau, E. Tison, K. Wilhelm: The structure and origin of solar plumes: Network plumes.
Astrophys. J. 700, 551-558 (2009)
- [4] J.M. Pasachoff, V. Rušin, M. Druckmüller, P. Aniol, M. Saniga, M. Minarovjech: The 2008 August 1 eclipse solar-minimum corona unraveled.
Astrophys. J. 702, 1297-1308 (2009)
- [5] Y.-M. Wang: Semiempirical Models of the Slow and Fast Solar Wind.
Space Sci. Rev. 172, 123-143 (2012)
- [6] K. Wilhelm, L. Abbo, F. Auchère, N. Barbey, L. Feng, A.H. Gabriel, S. Giordano, S. Imada, A. Llebaria, W.H. Matthaeus, G. Poletto, N.-E. Raouafi, S.T. Suess, L. Teriaca, Y.-M. Wang: Morphology, dynamics and plasma parameters of plumes and inter-plume regions in solar coronal holes.
Astron. Astrophys. Rev. 19:35, 1-70 (2011)