On how to estimate the far-side open flux using STEREO coronal holes

WHPI Workshop
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Stephan G. Heinemann[1] · Manuela Temmer[2] · Stefan J. Hofmeister[3] · Aleksandar Stojakovic[2] · Laurent Gizon[1,4,5] · Dan Yang[1]

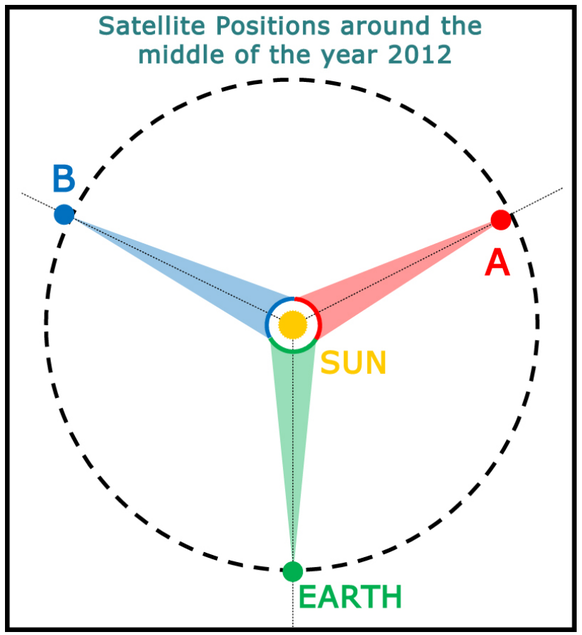
1 Max-Planck Institute for Solar System Research, Göttingen, Germany
2 Institute of Physics, University of Graz, Austria
3 Columbia Astrophysics Laboratory, Columbia University, New York, USA
4 Institut für Astrophysik, Georg-August-Universität Göttingen, Göttingen, Germany
5 Center for Space Science, NYUAD Institute, New York University Abu Dhabi, Abu Dhabi, UAE

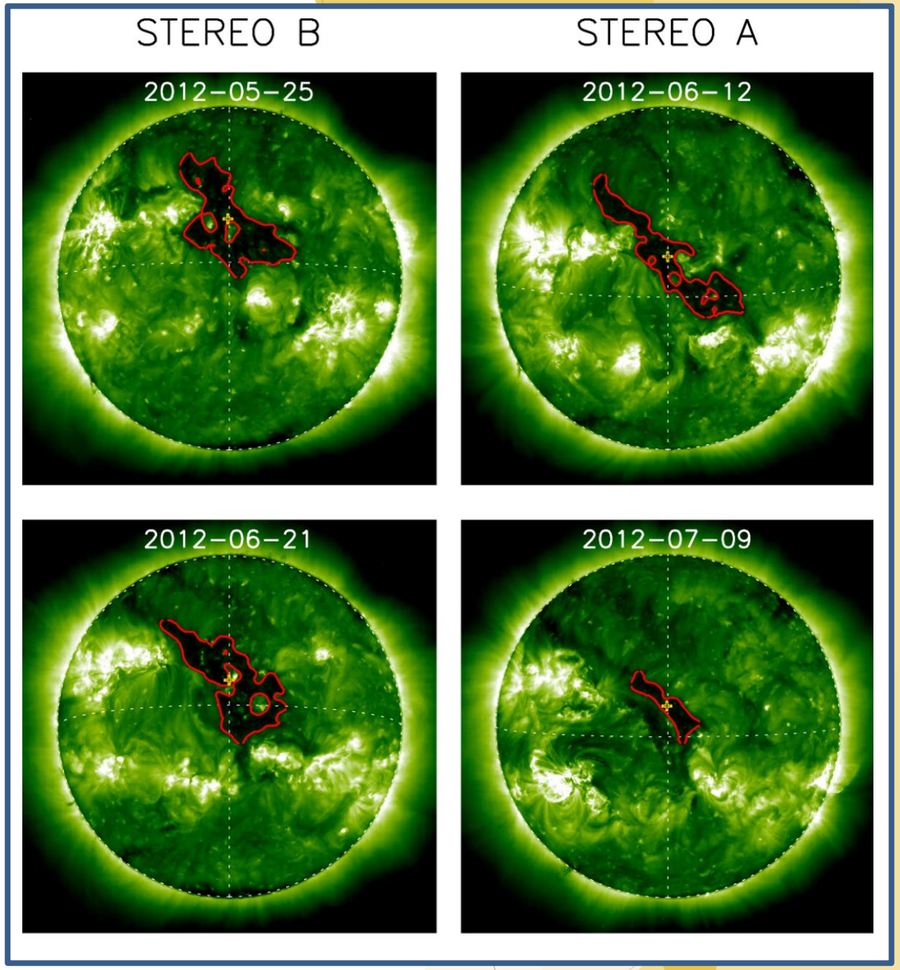
Motivation

- "Open Flux Problem"
  Remote sensing observations/model ≠ In-situ measured
  (Linker+ 2017, Linker+ 2021)

- Magnetic information only from the front side (kind of)
  "aging effects" in the 360° information

- How can we observe/measure/estimate the far side open flux?





From Heinemann+ (2018)

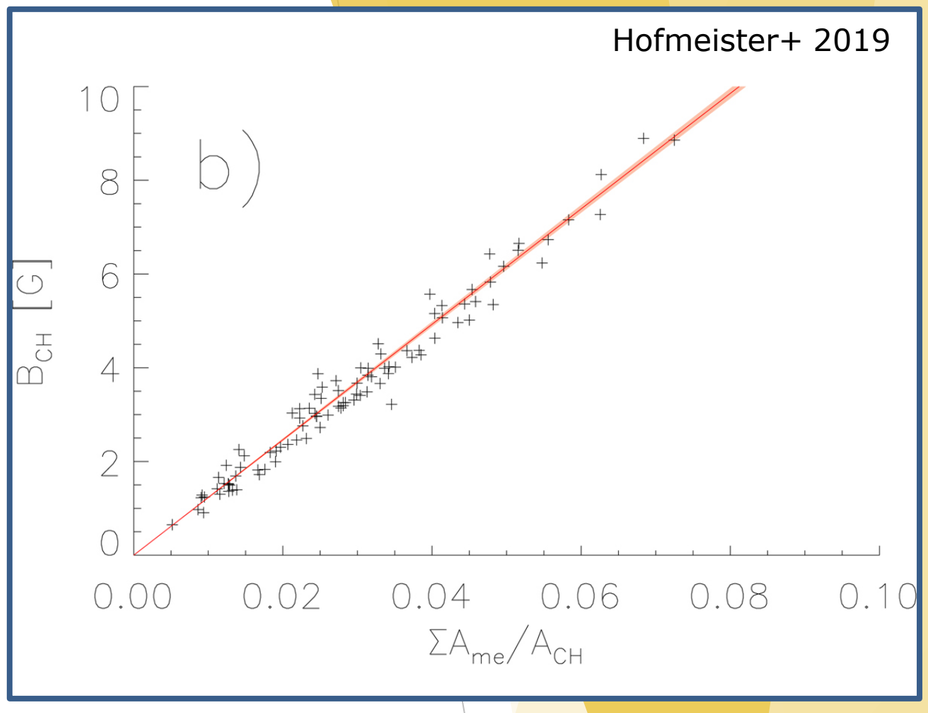
STEREO CORONAL HOLES ?

Structure of Coronal Holes

Rooted in unipolar magnetic elements of dominant magnetic polarity that define the coronal holes magnetic flux (Hofmeister+ 2019)

$A_{ME}[\%]$ – B_{CH} Relation

Photospheric footpoints of open fields



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$A_{ME}[\%]$ – B_{CH} Relation

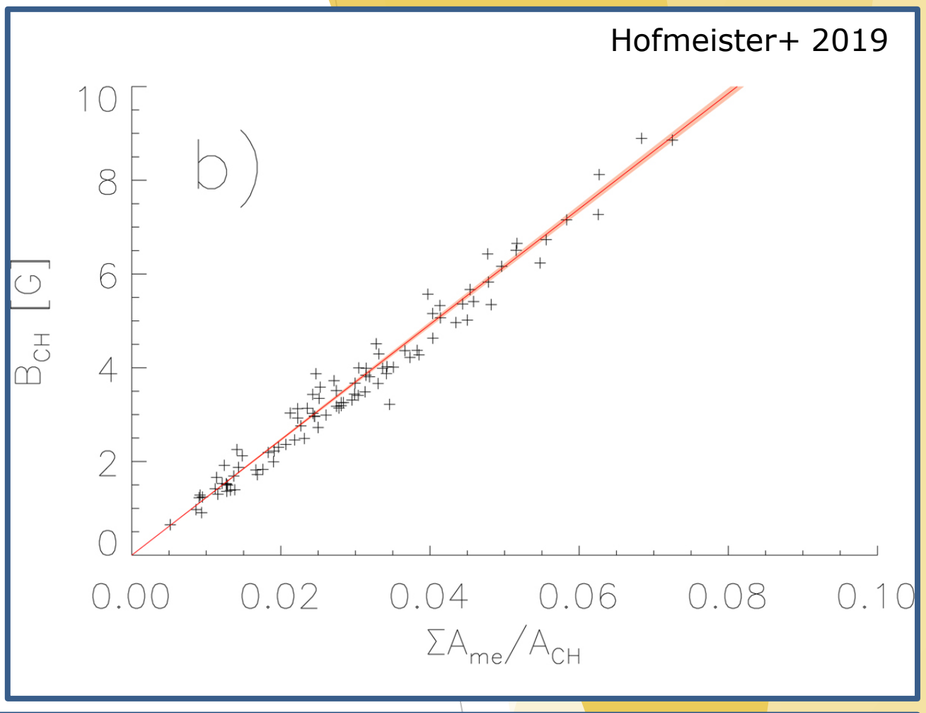
Photospheric footpoints of open fields

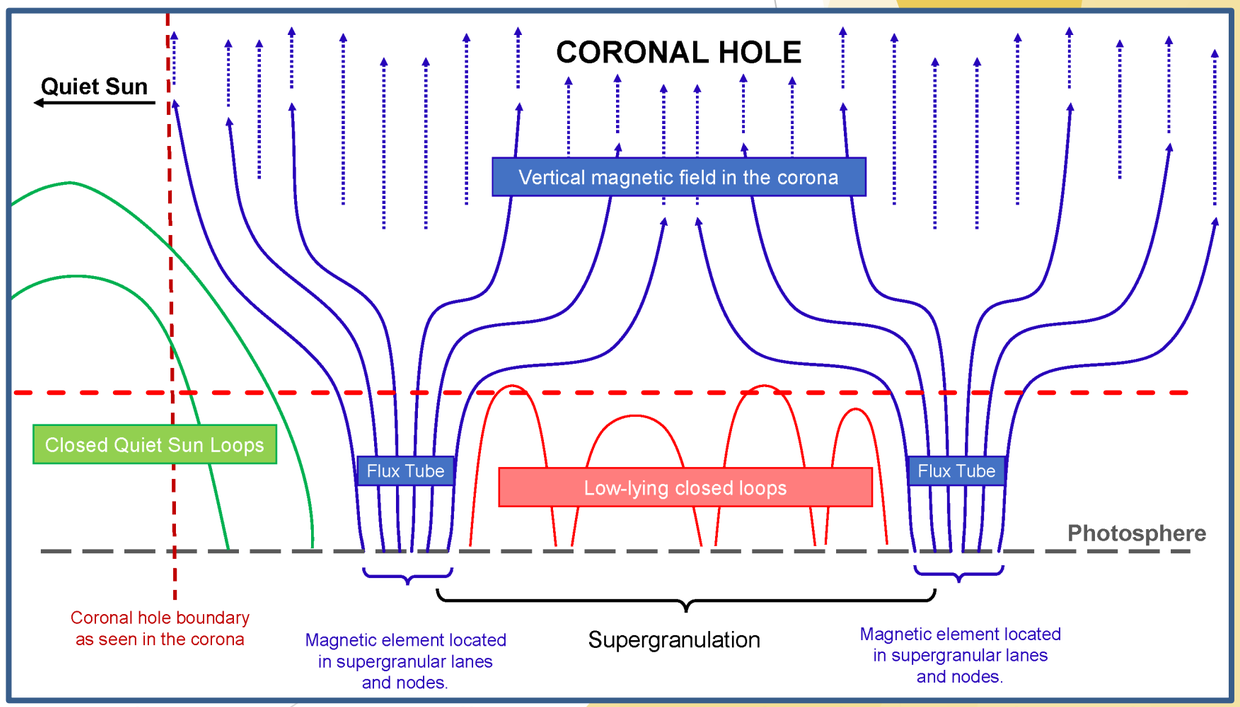
Field expands upwards, to eventually form a roughly uniform vertical field
(e.g., Cranmer & van Ballegooijen, 2005)

How do coronal holes appear in the chromosphere?

Chromosphere?

Can we extract magnetic information?





Based on cartoons by Cranmer & van Ballegooijen, 2005 and Wedemeyer-Böhm et al. 2009.

Structure of Coronal Holes

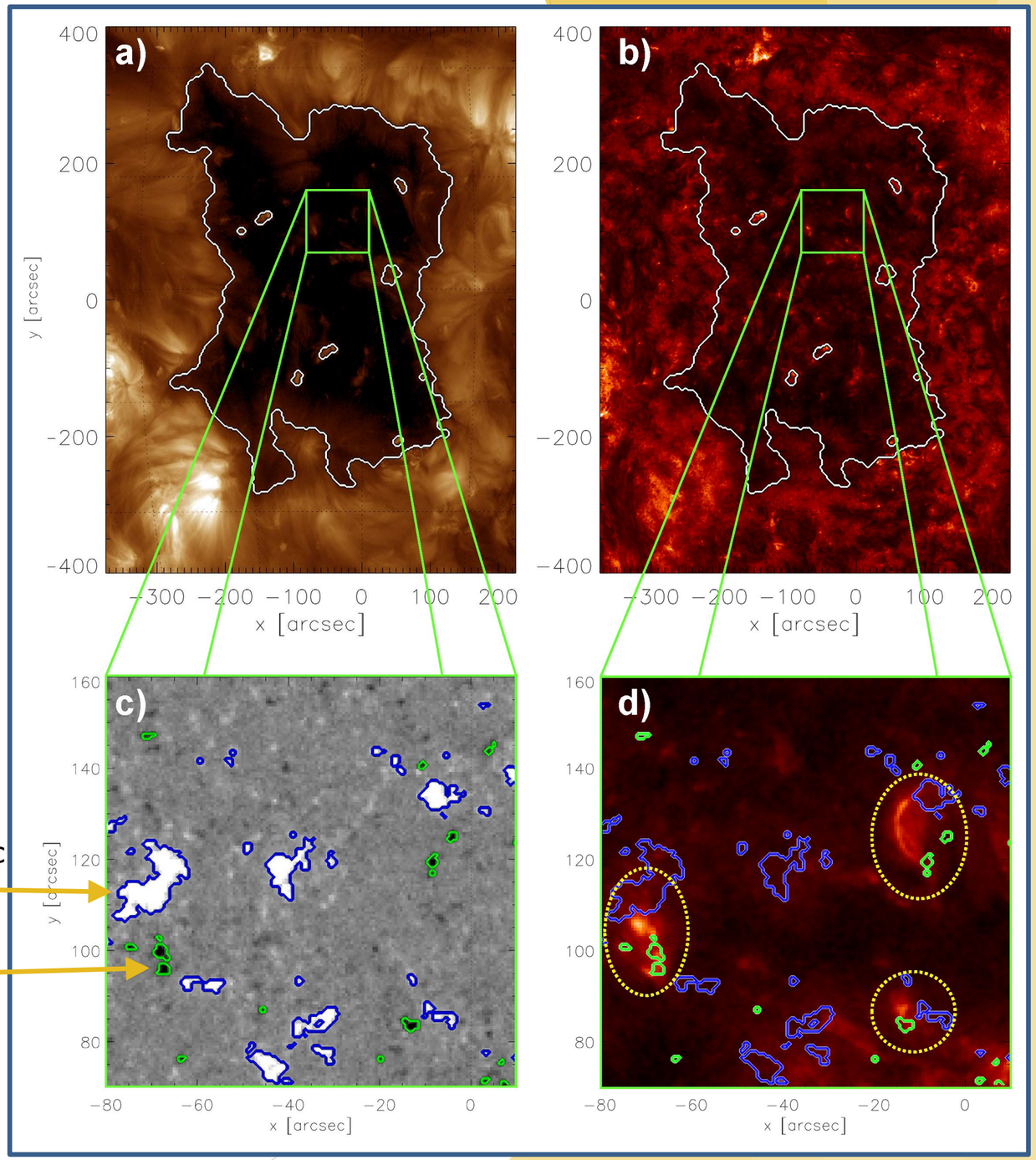
Photosphere:
Magnetic elements cover ~1-10% A_{CH}
-> define the signed flux = open field

Chromosphere:
Bright structures -> Bi-polar, proxy for closed loops

Small scale closed loops in coronal hole are lower than in the quiet sun. (Wiegelmann & Solanki, 2004)

Assumption:
Open "vertical" fields already fill most of the space at chromospheric heights.

Only stronger closed loops extend that far upwards -> bright



Heinemann+ (2021)

Data

A_{ME} – B_{CH} relation is known for the photosphere -> does it exist for the chromosphere/304Å ?

- 313 SDO coronal holes from CATCH (Collection of Analysis Tools for Coronal Holes) → to establish the correlation between the magnetic field and the 304Å coronal holes

HMI - magnetic field AIA – chromosphere (304Å) AIA – corona (193Å)

- 657 quiet Sun (SDO) subfields of a size of 150”×150”

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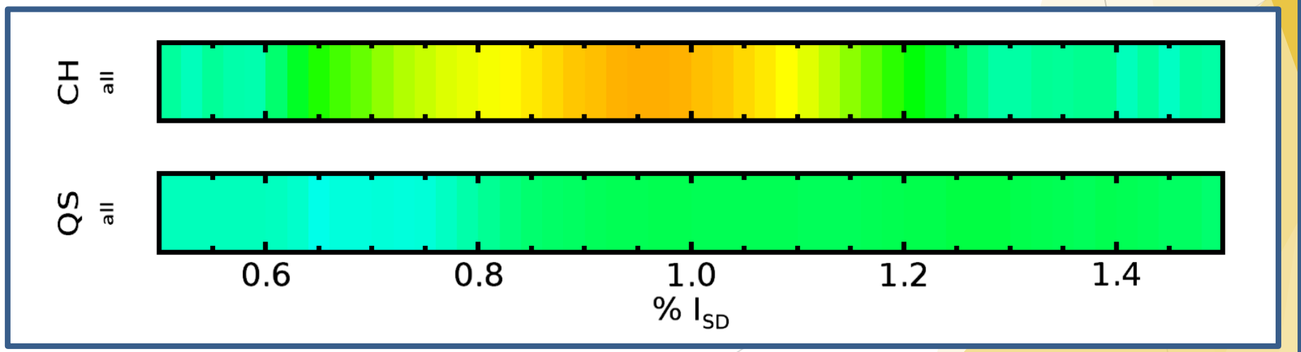
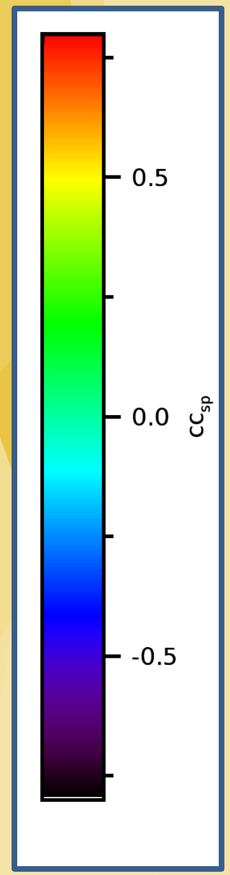
Correlation of mean magnetic flux density ($|B_{ch}|$) of the coronal hole and the percentage area coverage (A_{of}) of the coronal holes (below a set intensity threshold) as function of the threshold normalized to the solar disk median intensity (I_{SD})

Max @ 0.94

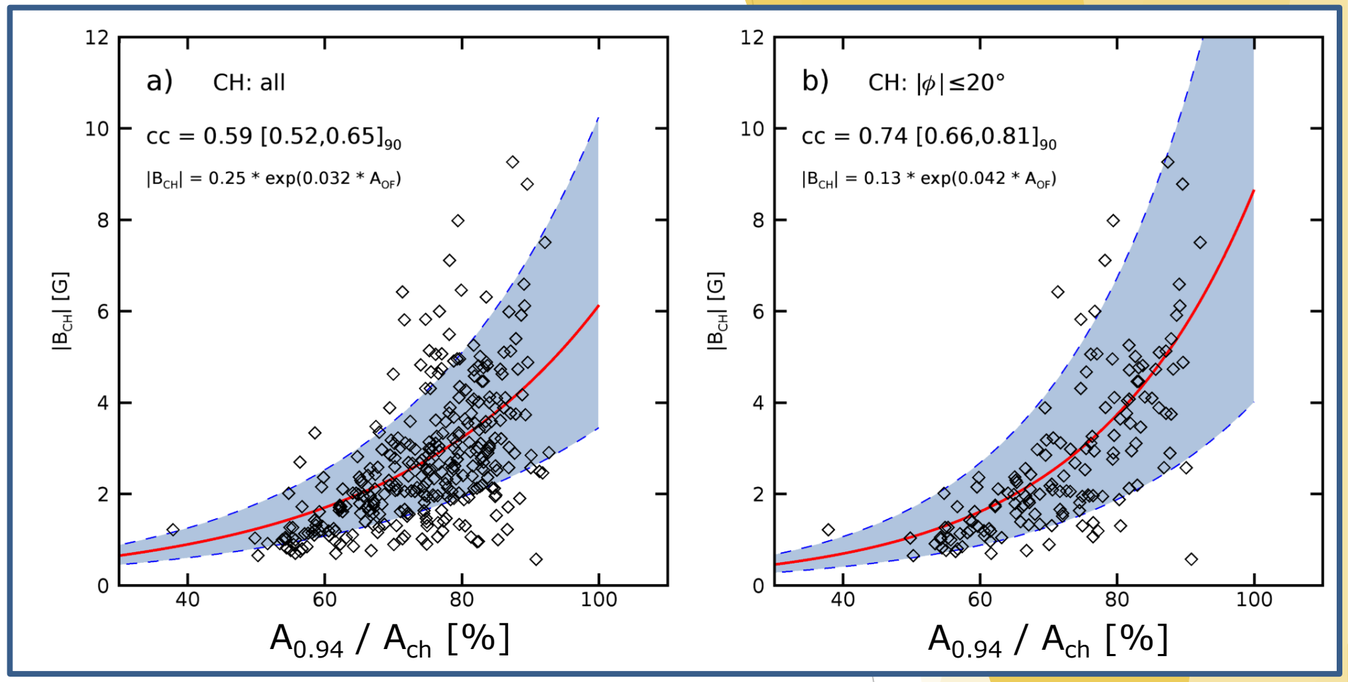




Heinemann+ (2021)

Results

For a threshold of 0.94 I_{SD}
cc = 0.59
cc = 0.74 (CHs in the disk center)



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Heinemann+ (2021)

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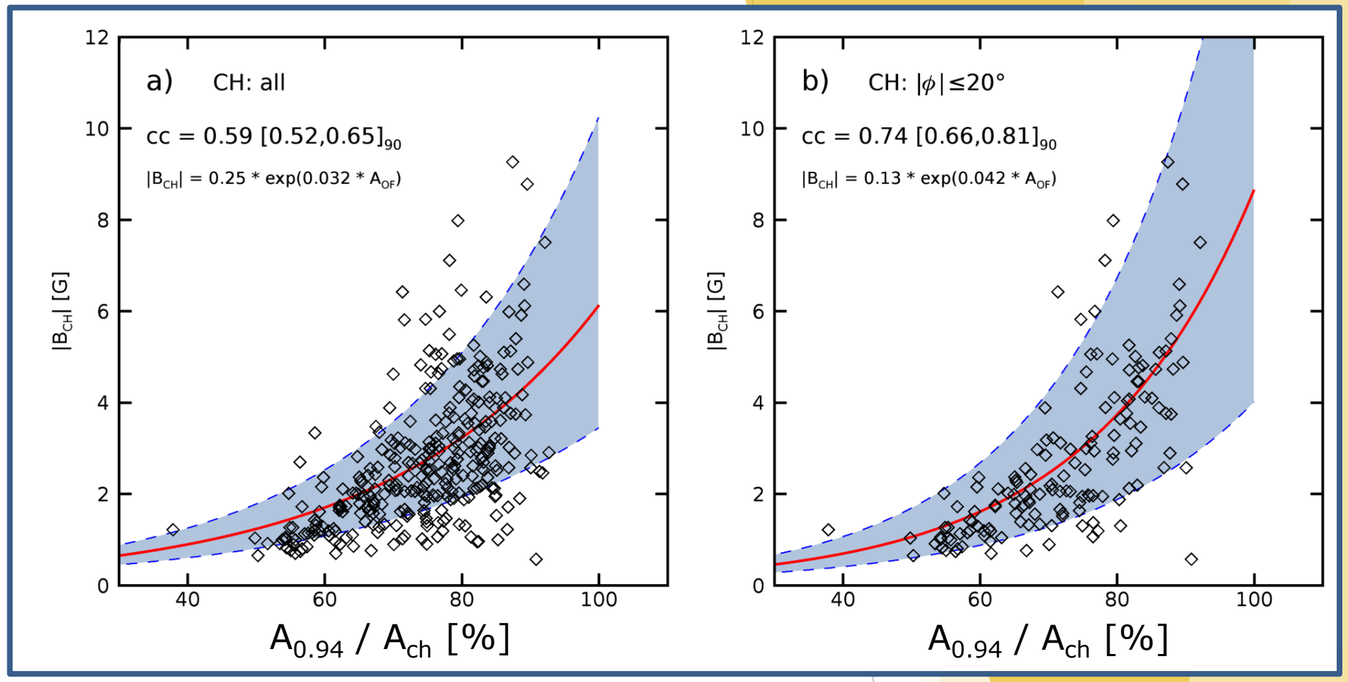


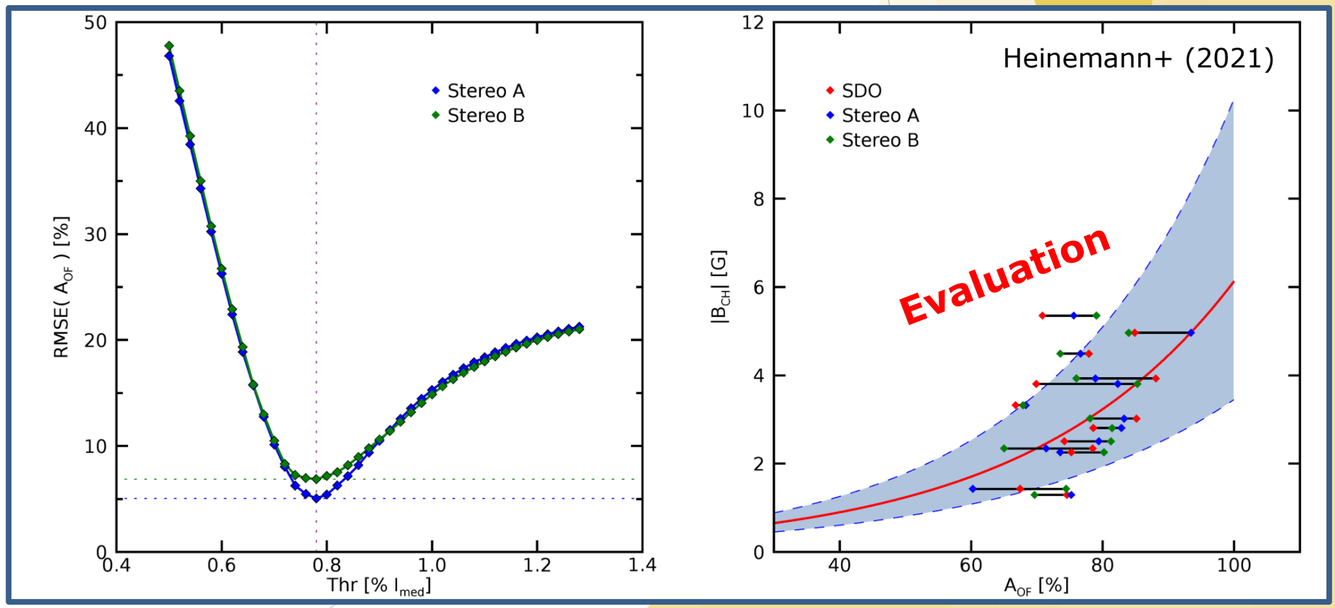
Relation exists for SDO

Assumption that the Relation is valid for STEREO data

Calibrate STEREO threshold to the SDO threshold

- 13 coronal holes in 2010/2011
- Low separation (<90°) between SDO and STEREO
- Low evolutionary change (<½ G)

$0.78^{STEREO} * I_{SD} \sim 0.94^{SDO} * I_{SD}$



Summary

- Intensity distribution of 304Å observations in coronal holes significantly differs to quiet Sun regions.
- Area coverage of photospheric magnetic elements of coronal holes can be approximated in 304Å by the area proportion below a threshold of 78% (STEREO) or 94% (SDO) of the solar disk median intensity.
- We successfully calibrated the area ratios for SDO and STEREO (RMSE<10%A_{of}; ME<1%A_{of}). This allows the use of the found relation on STEREO data.
- From the relation between the area coverage (A_{of}) in 304Å and signed mean magnetic flux density ($|B_{ch}|$), we derived that the open flux of a coronal hole can be approximated as:

$$|\Phi_{ch}| = (0.25 \pm 0.06) * A_{ch} * e^{(0.032 \pm 0.003) * A_{of}}$$

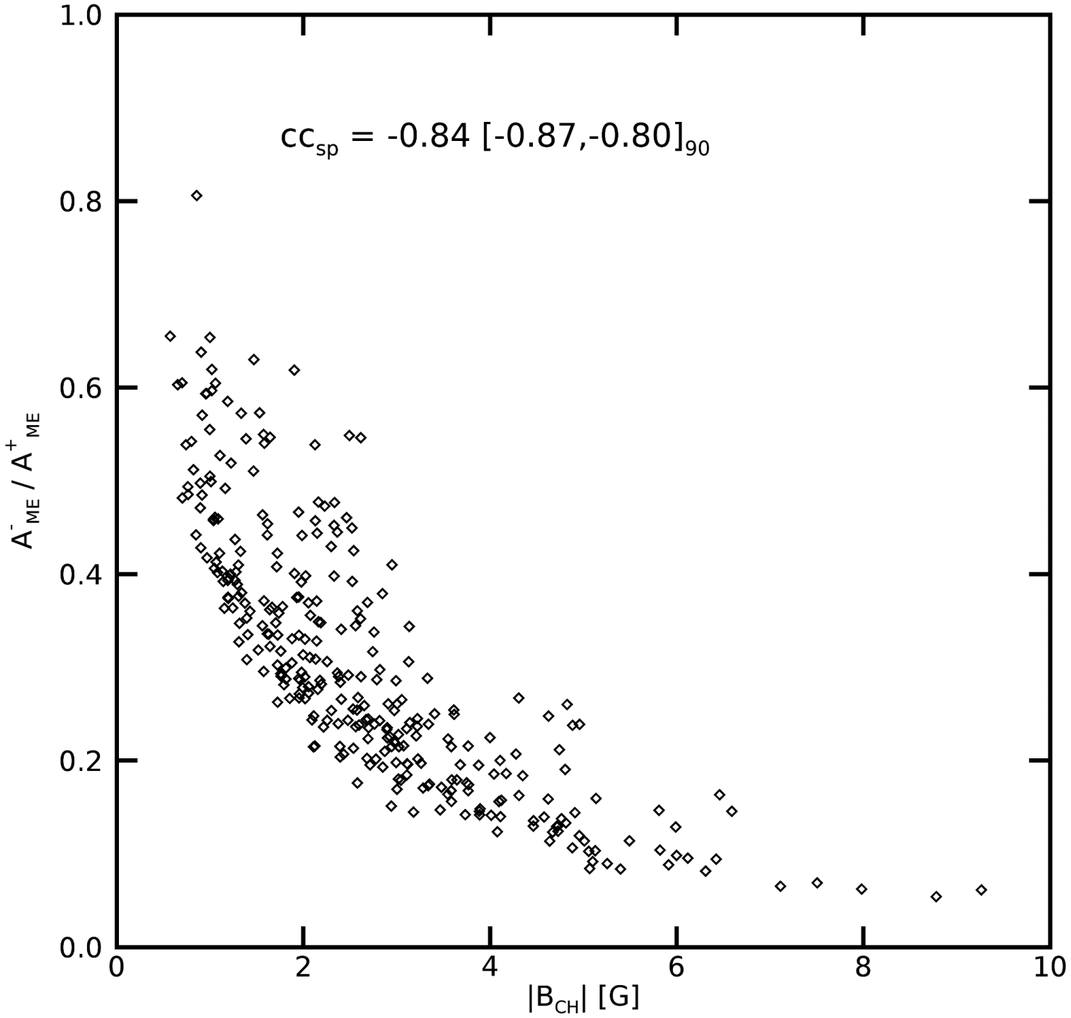
Thank you for your attention!

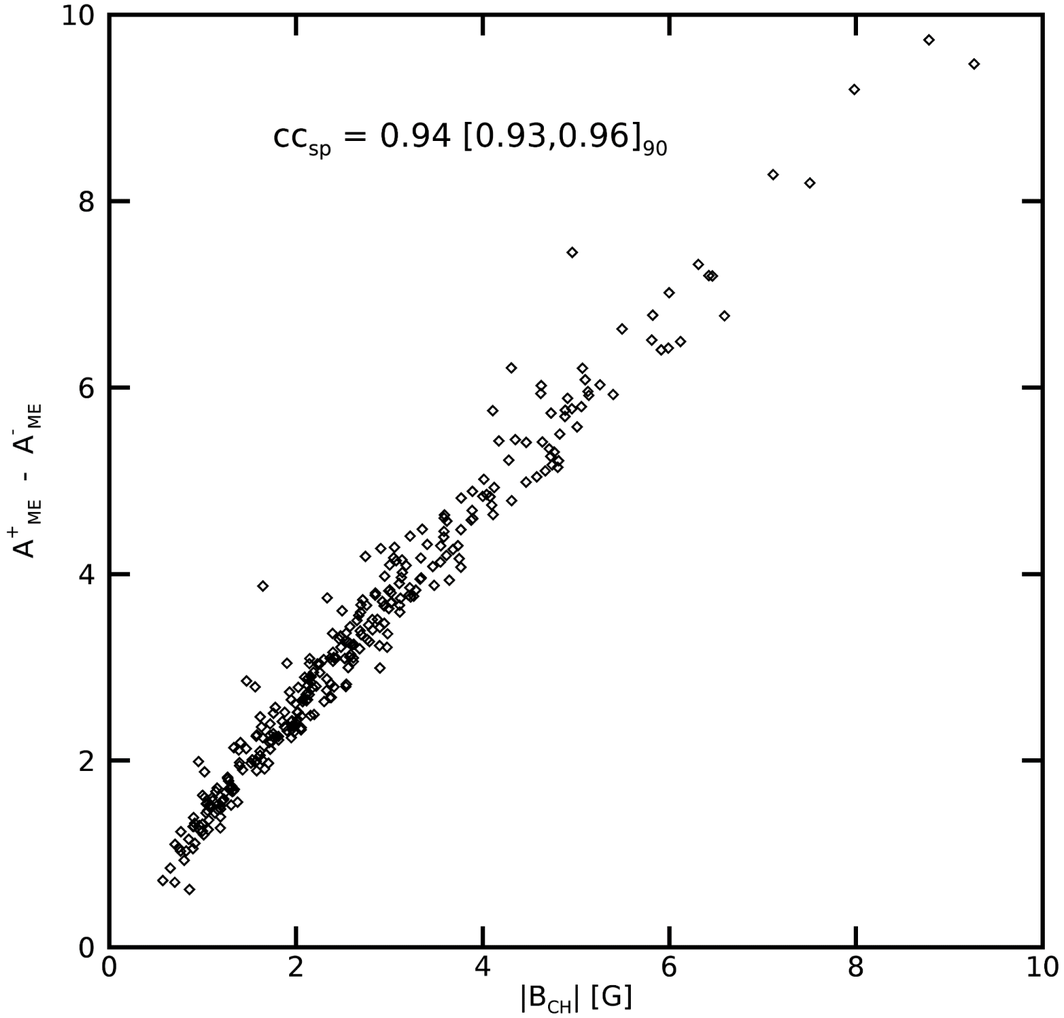
CATCH
Collection of Analysis Tools for Coronal Holes

Paper

Heinemann et al., (2021), accepted in Solar Physics
https://arxiv.org/abs/2109.02375

Further information





Further information