

Density measurements at the base of the solar wind

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Why is the coronal hole density useful?

- The fast solar wind is believed to originate in coronal holes
- Models of the fast solar wind require boundary conditions defined in the Sun's low atmosphere
- Electron density (pressure) is one of the boundary parameters
- Also valuable to spectroscopists for checking diagnostics and atomic data
- Observation requirements:
 - look on the disk to avoid line-of-sight effects
 - density diagnostics formed at $\log T = 5.8-6.2$

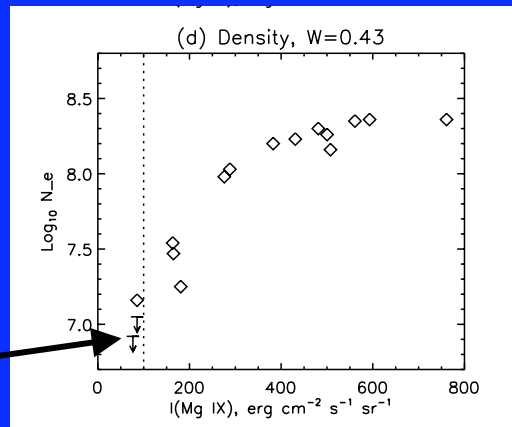
Standard picture

Coronal hole density $\approx 1-2 \times 10^8 \text{ cm}^{-3}$

Quiet Sun density $\approx 3-4 \times 10^8 \text{ cm}^{-3}$

Previous work – on disk

- *Skylab*
 - Esser et al. (1998, ApJ) derived densities of $7\text{--}20 \times 10^7 \text{ cm}^{-3}$ from Mg VIII
- SOHO/CDS
 - Del Zanna & Bromage (1999, JGR) derived densities of $2\text{--}3 \times 10^8 \text{ cm}^{-3}$ using Si IX
 - Young & Esser (1999a,b conf. proceedings) derived much lower densities ($\log N_e = 7.0 - 7.5$) from Si IX and Mg VIII

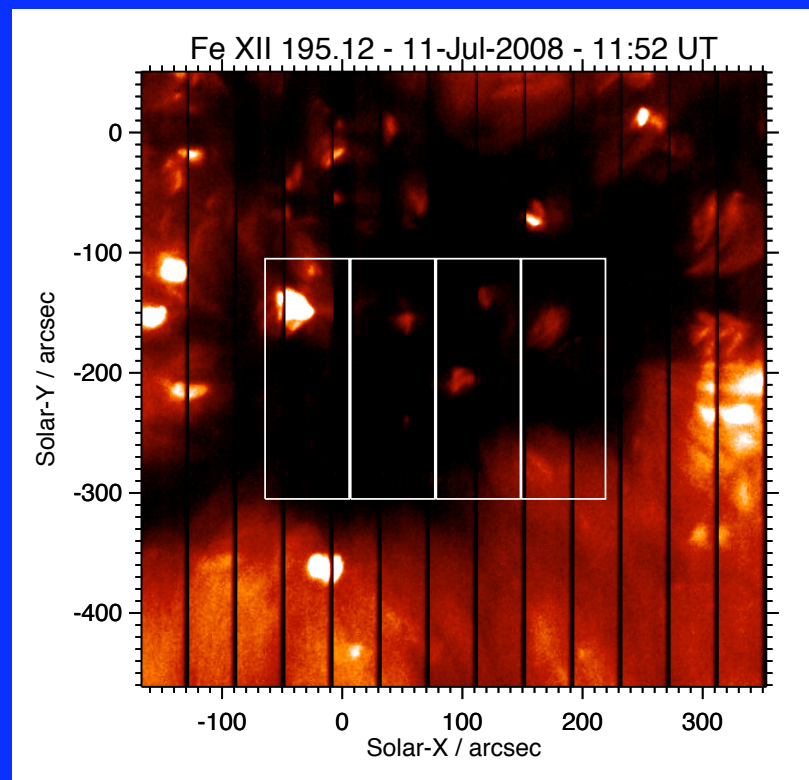
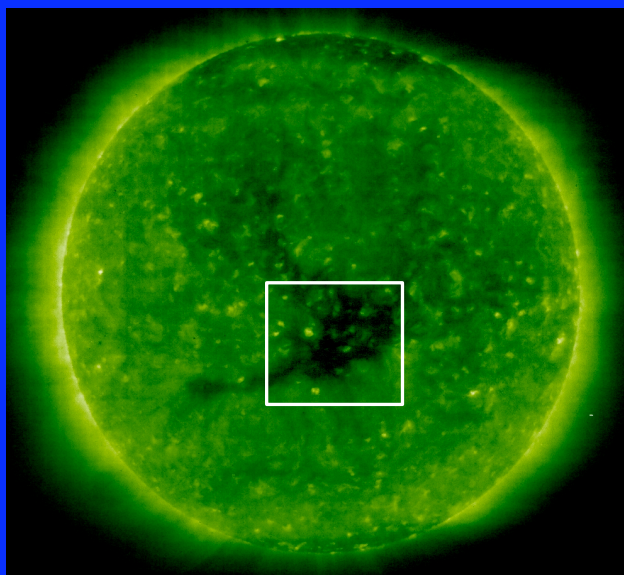


Low densities found in darkest regions

Necessary to include *photoexcitation* in atomic models

Example coronal hole – 11 July 2008

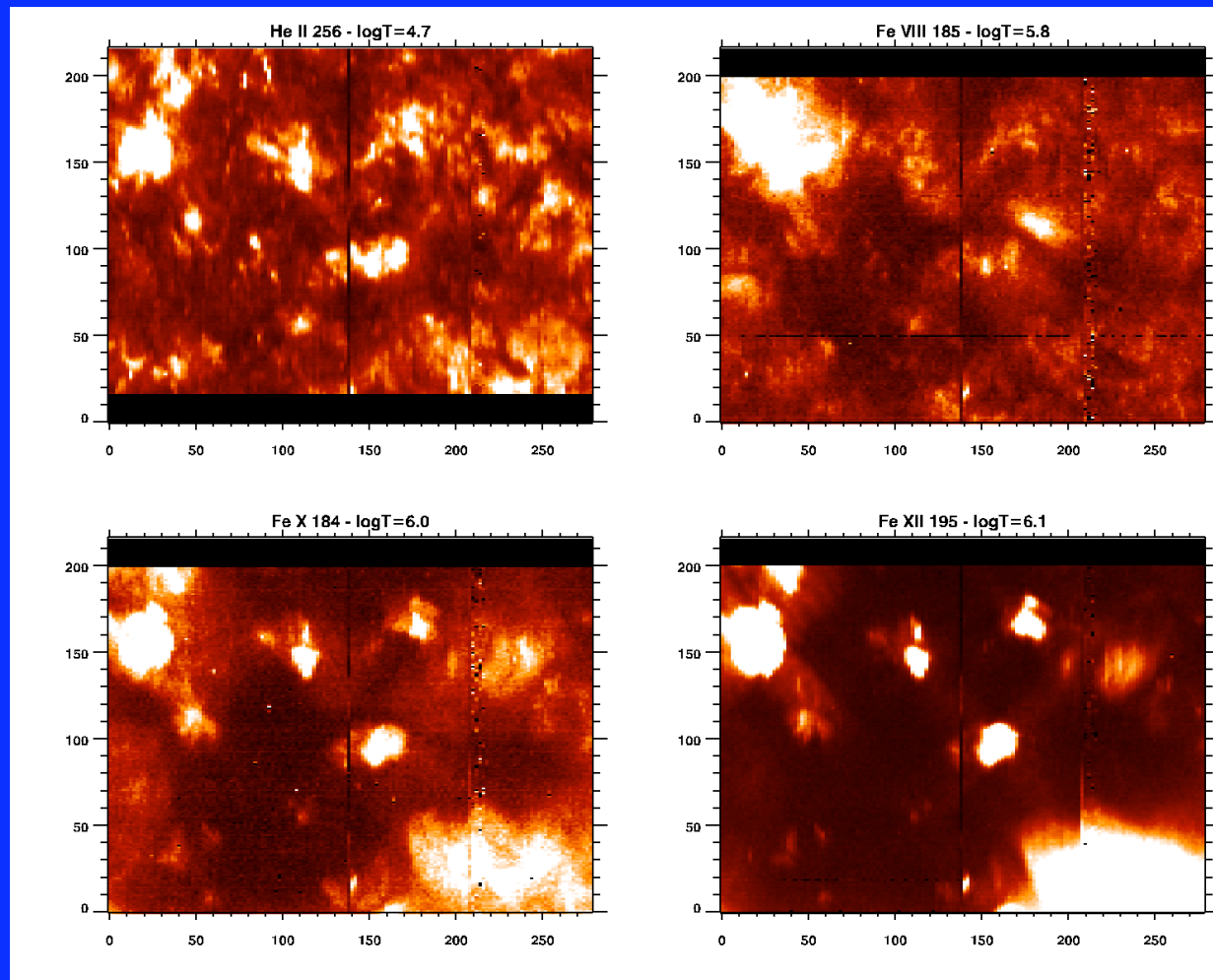
- Large equatorial coronal hole



(Thanks to EIS CO, Yokoyama-san, for excellent observation!)

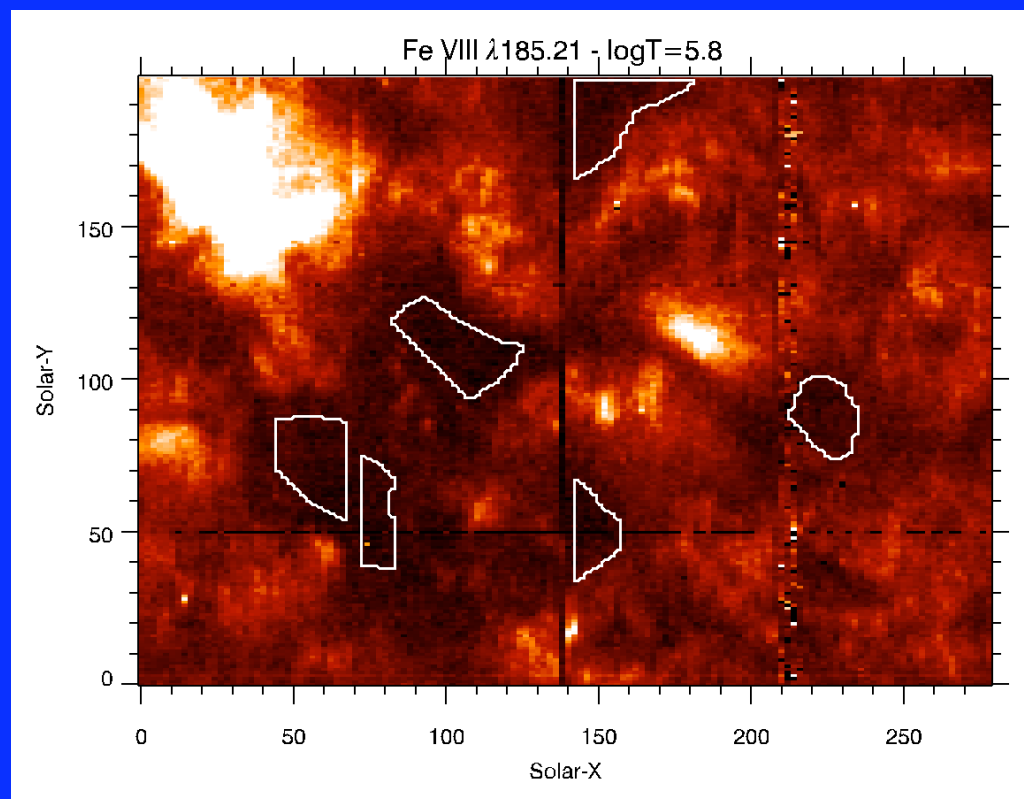
Example coronal hole – 11 July 2008

- EIS monochromatic raster images



Coronal hole selection

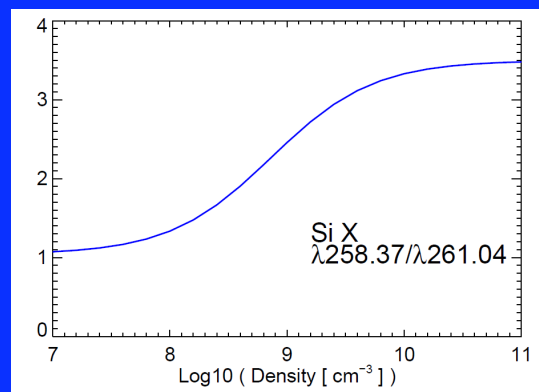
- Six dark coronal hole areas identified in Fe VIII $\lambda 185.21$ image
- Spatial pixels summed to yield six coronal hole spectra



EIS coronal hole density diagnostics

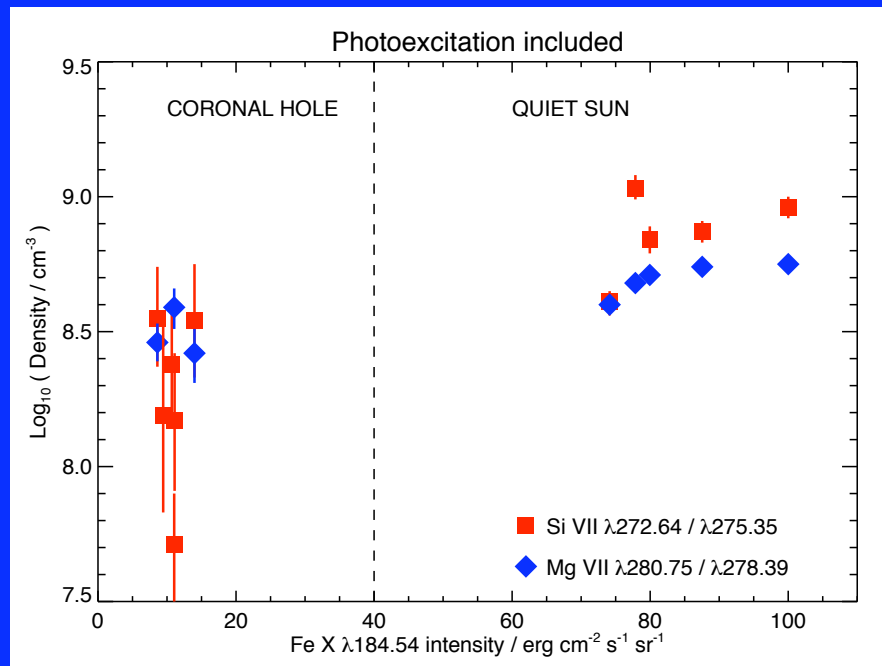
Ion	Ratio	Log (T/K)	Photoexc.?
Mg VII	$\lambda 280.75 / \lambda 278.39$	5.8	No
Si VII	$\lambda 272.64 / \lambda 275.35$	5.8	Yes
Fe VIII	$\lambda 186.60 / \lambda 185.21$	5.8	Yes
Fe X	$\lambda 257.26 / \lambda 184.54$	6.0	No
Si X	$\lambda 258.37 / \lambda 261.04$	6.1	Yes
Fe XII	$\lambda 186.88 / \lambda 195.12$	6.1	No

Atomic data from v5.2 of CHIANTI, except Mg VII which are from (soon-to-be-released) v6.0



Mg VII & Si VII diagnostics ($\log T=5.8$)

- Si VII is sensitive to photoexcitation

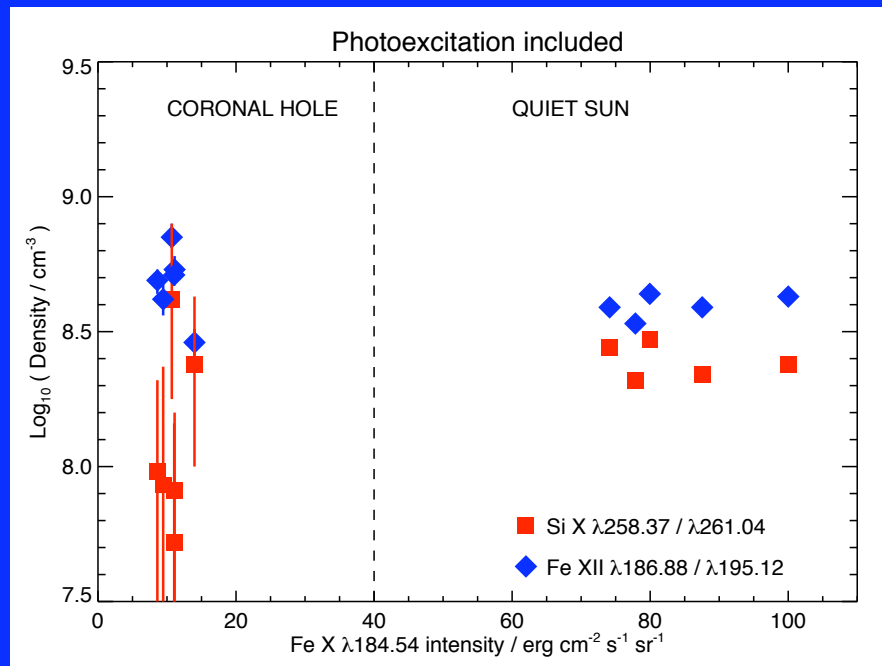


Ion	CH Dens	QS Dens	CH Pressure	QS Pressure
Si VII	8.26	8.86	14.06	14.66
Mg VII	(8.58)	8.78	(14.38)	14.58

(Log₁₀ values)

Si X & Fe XII diagnostics ($\log T=6.1$)

- Si X is sensitive to photoexcitation

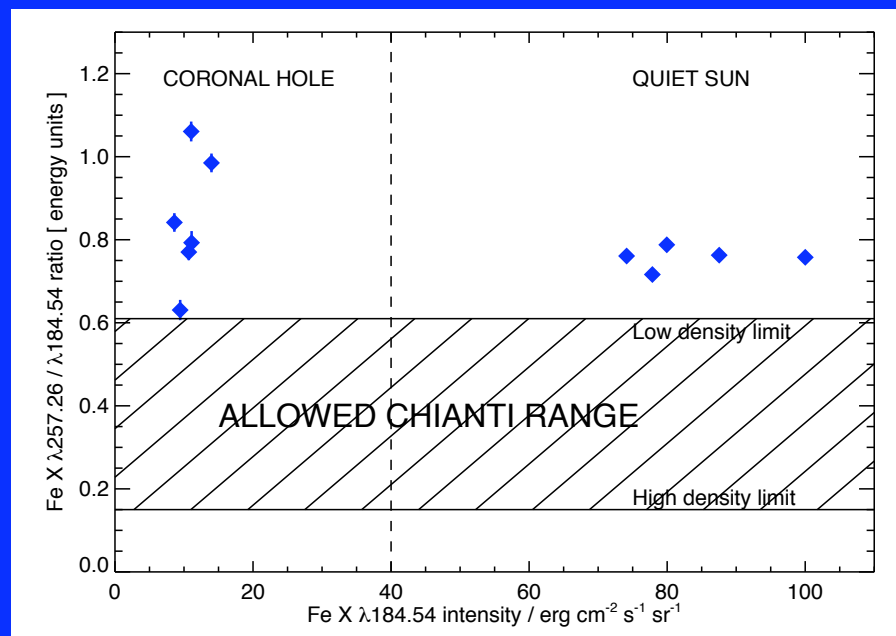


Ion	CH Dens	QS Dens	CH Pressure	QS Pressure
Si X	8.17	8.39	14.27	14.49
Fe XII	8.67	8.58	14.77	14.68

(Log₁₀ values)

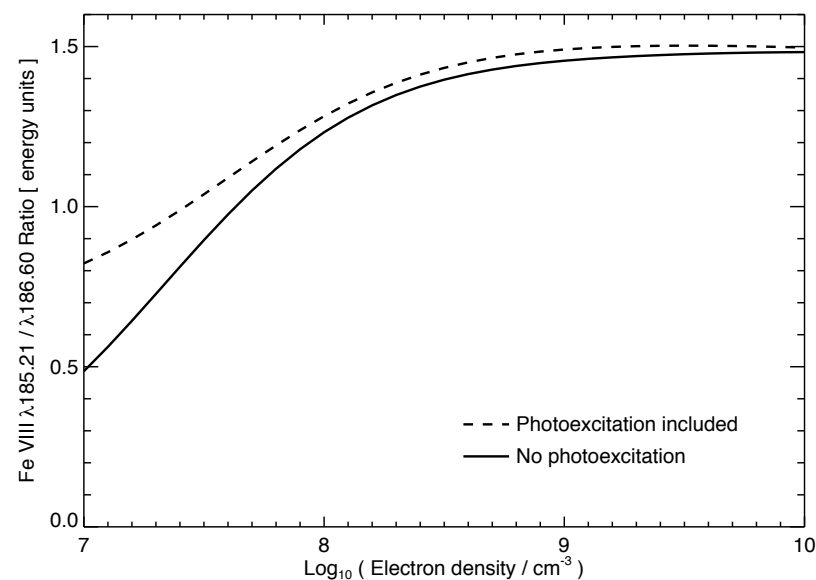
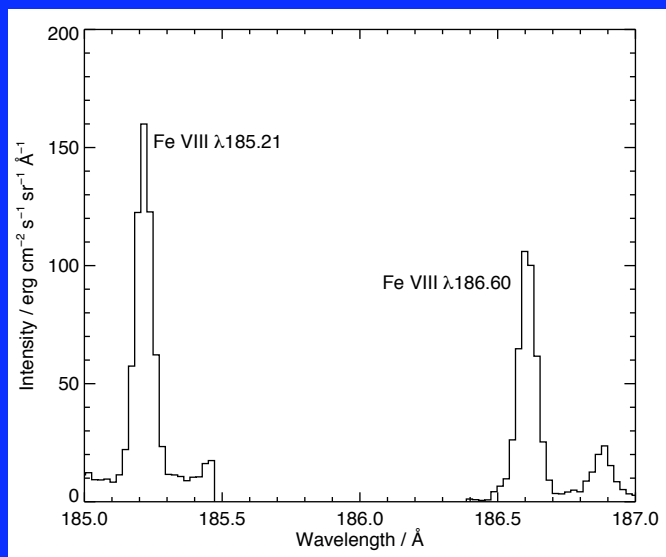
Fe X λ 184.54 / λ 257.26

- In both quiet Sun and coronal holes the measured Fe X ratios are above the low density limit
- The coronal hole values are higher than the quiet Sun values
- Implies ratio is diagnosing density differences...
- ...*but*, measurements inconsistent with atomic theory



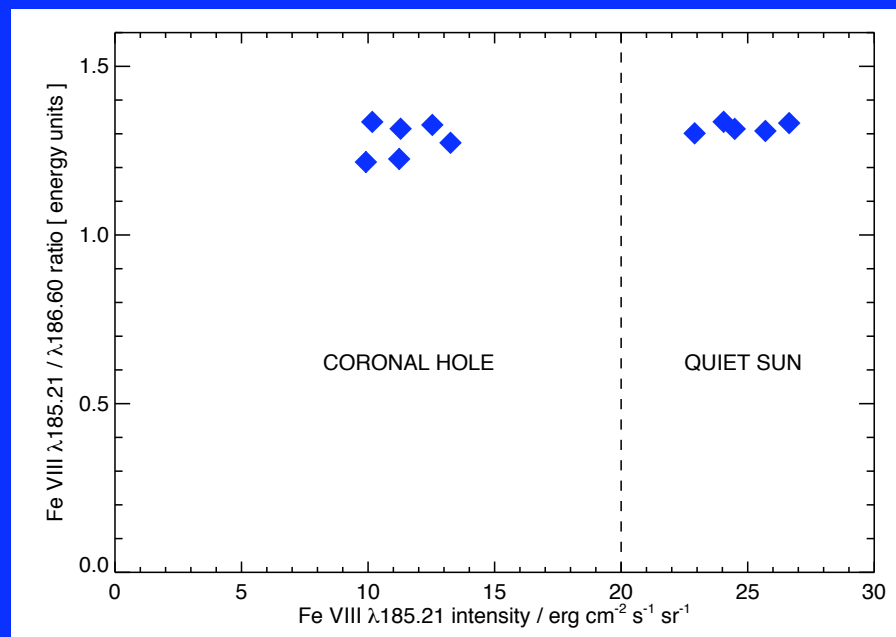
Fe VIII λ 185.21 / λ 186.60

- Both lines are strong in coronal hole spectra and comparable in intensity
- Ratio sensitive to photoexcitation



Fe VIII λ 185.21 / λ 186.60

- Ratio approximately constant in coronal holes and quiet Sun



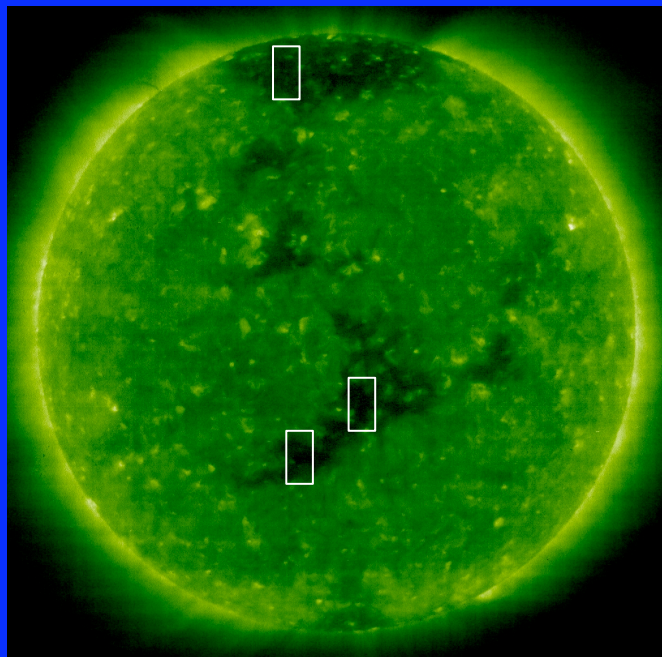
- Taking average ratio values gives:
 - coronal hole density: $\log N_e = 7.99$
 - quiet Sun density: $\log N_e = 8.09$

Conclusions

- No evidence is found for the very low densities found by Young & Esser (1999a,b)
- Different ions show inconsistent results
 - Si VII, Mg VII, Si X show lower CH densities by 0.2-0.6 dex compared to QS
 - Fe VIII & Fe XII show same density in CH and QS
 - Fe X measurements inconsistent with theory
- Further work
 - need to investigate 'deep-cleaning' of CCD warm pixels
 - update atomic data (Si VII, Si X, Fe X)

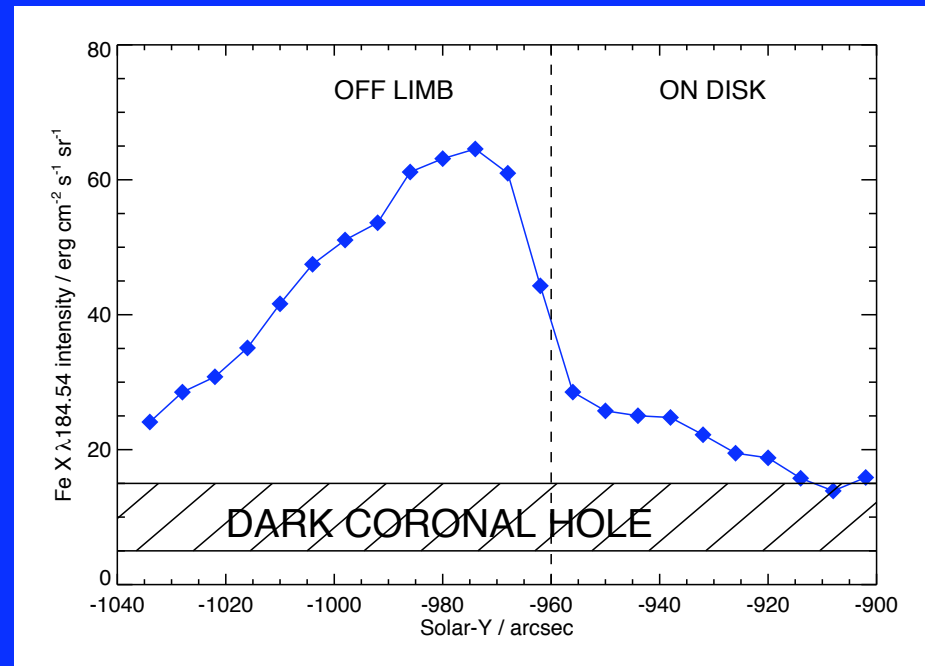
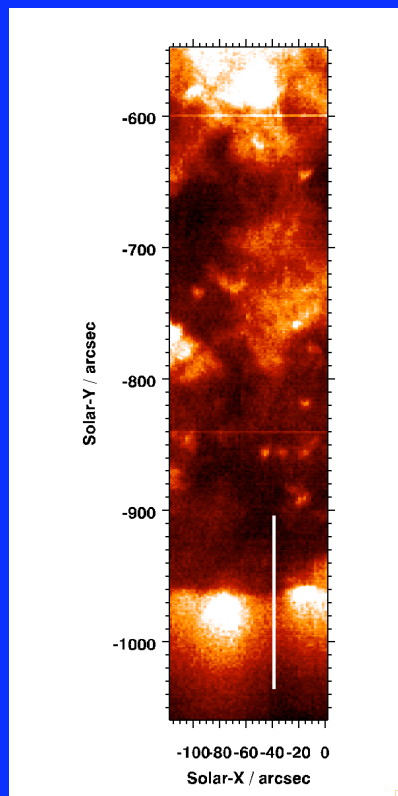
Note for EIS Chief Observers

- Please run my study PRY_CH_density if you see a nice coronal hole!
- Low data volume study optimised for S-band operations



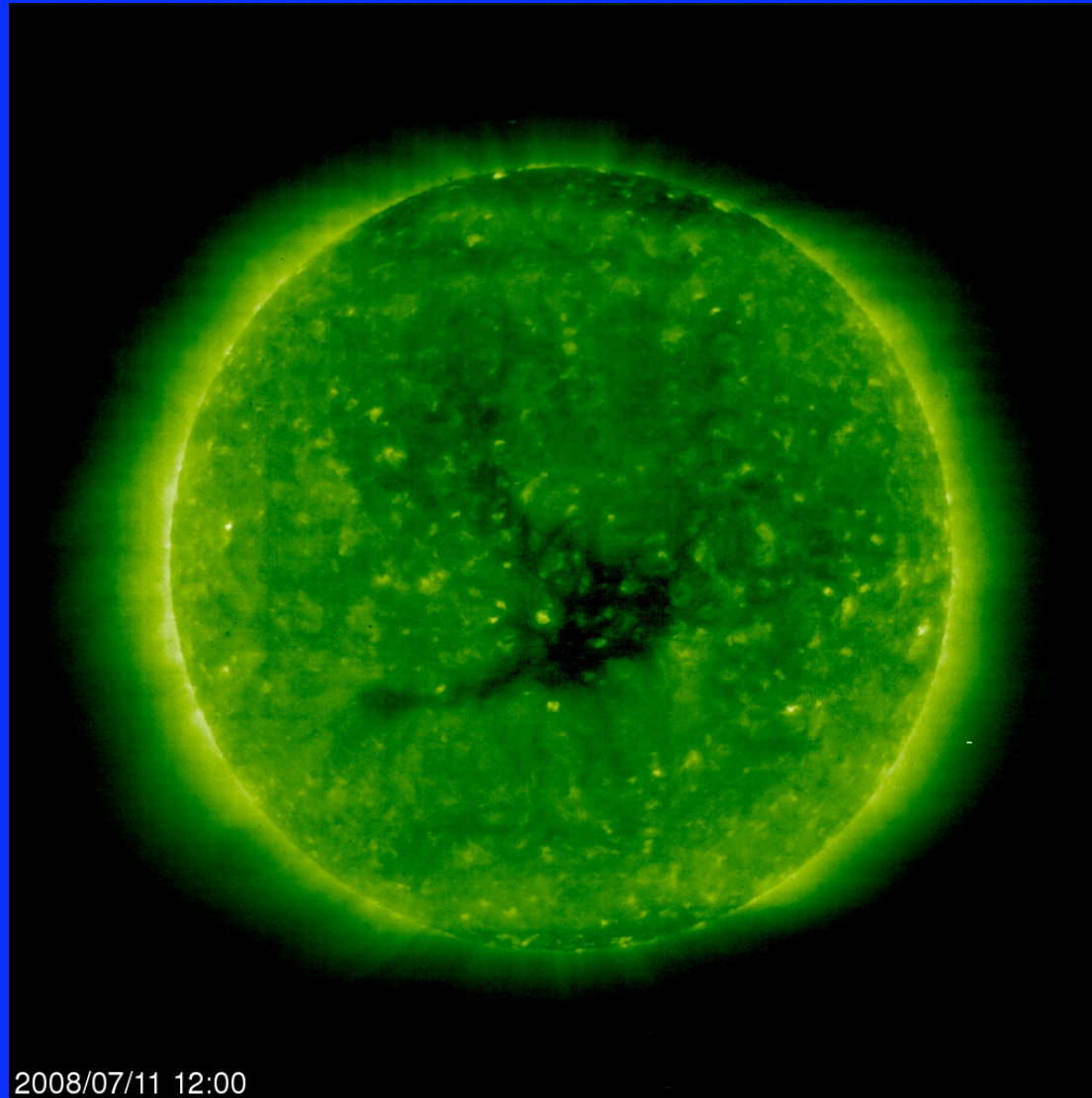
Off-limb vs. on disk

- Off-limb coronal hole spectra are contaminated by non-coronal hole regions



Fe X λ 184.54, 19-Jan-08, 13:35

Coronal holes



2008/07/11 12:00

SOHO/EIT
Fe XII 195

Hinode / EIS

2nd Hinode Science Meeting, Boulder, Sep 2008