Density measurements at the base of the solar wind

Dr Peter Young
Naval Research Laboratory
George Mason University

Hinode / EIS

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 ≈ 1-2 × 10^8 cm^{-3}

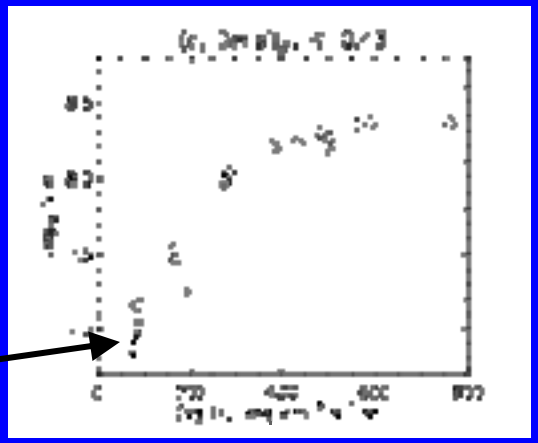
Quiet Sun density ≈ 3-4 × 10^8 cm^{-3}

Hinode / EIS

Previous work – on disk

- *Skylab*
  - Esser et al. (1998, ApJ) derived densities of 7-20 x 10^7 cm^{-3} from Mg VIII
- SOHO/CDS
  - Del Zanna & Bromage (1999, JGR) derived densities of 2-3 x 10^8 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

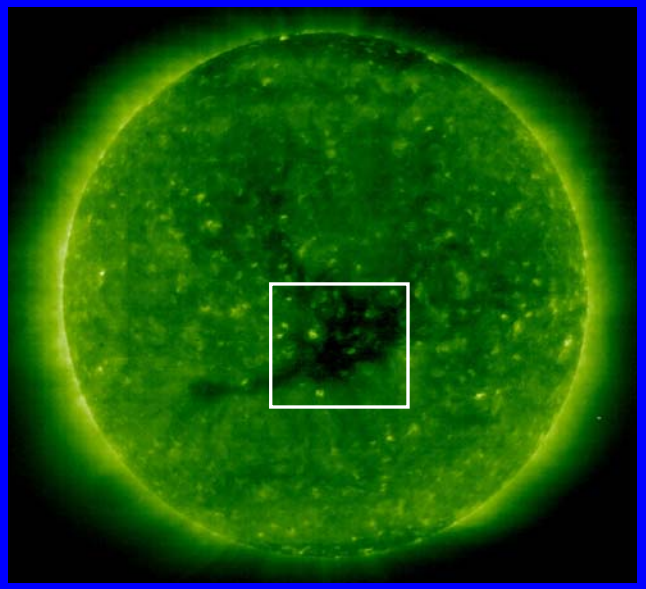
Low densities found in darkest regions

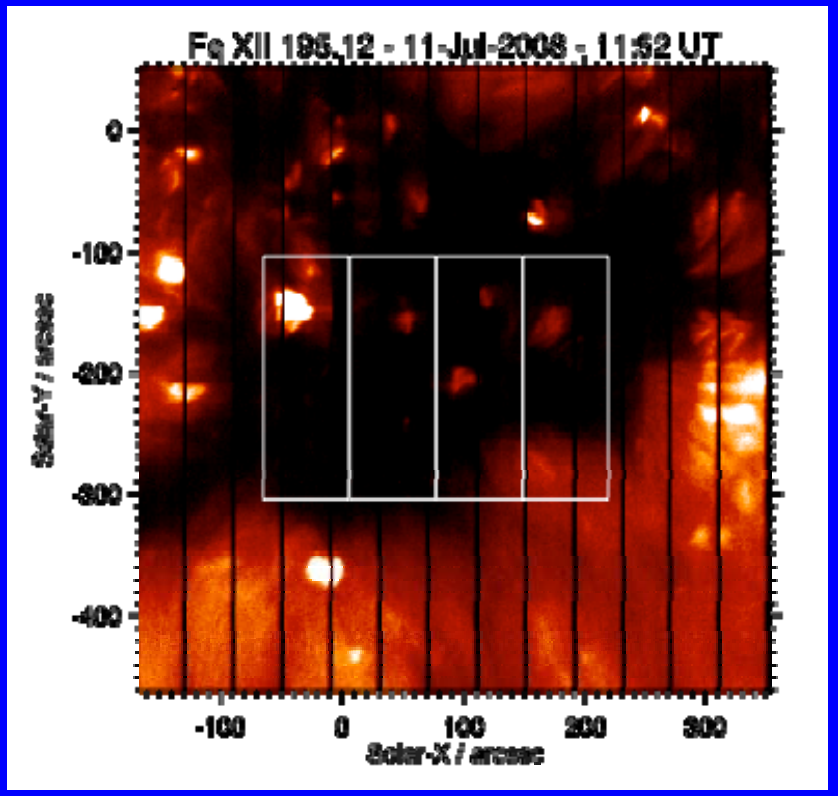


Necessary to include *photoexcitation* in atomic models

Example coronal hole – 11 July 2008

- Large equatorial coronal hole

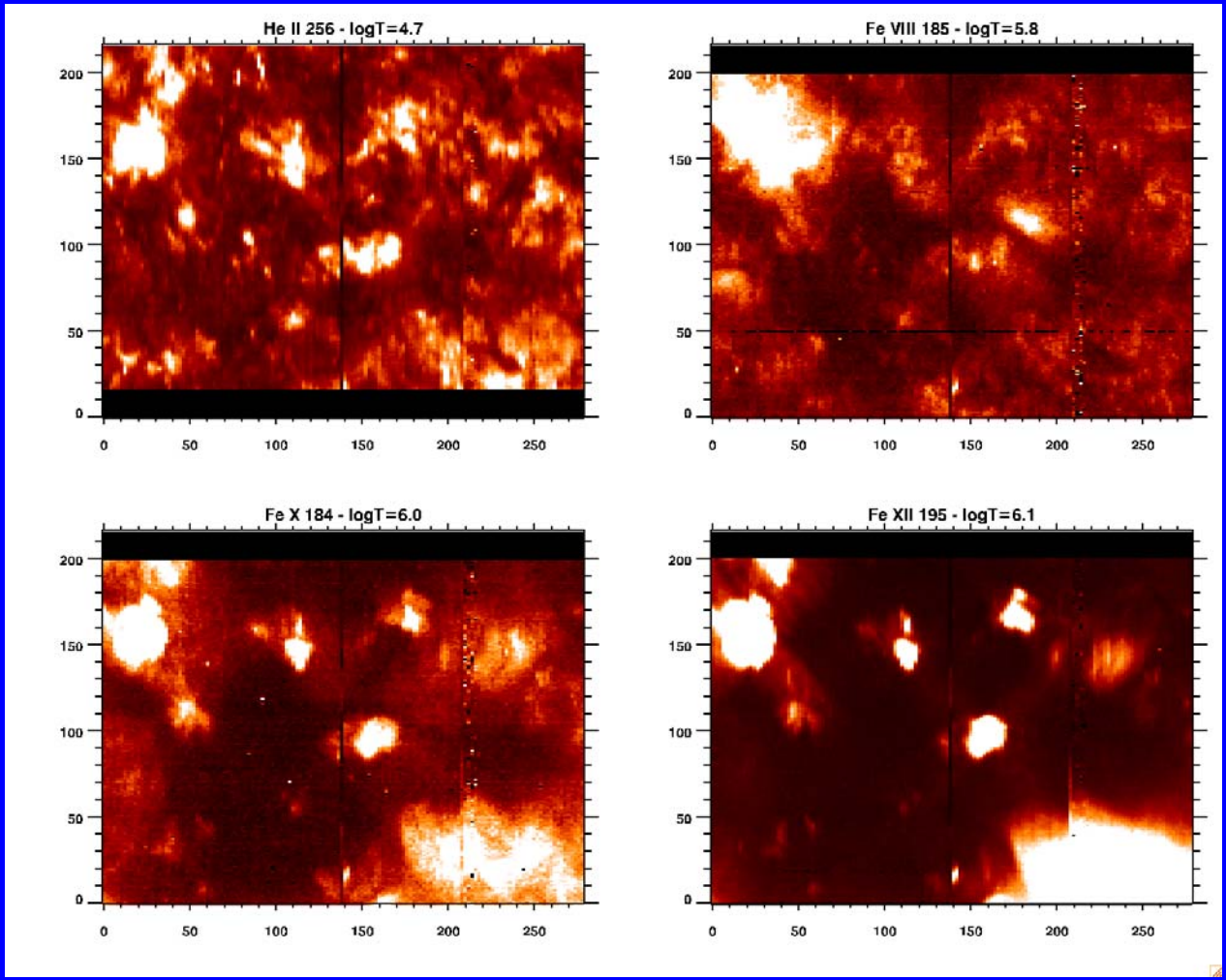




(Thanks to EIS CO, Yokoyama-san, for excellent observation!)

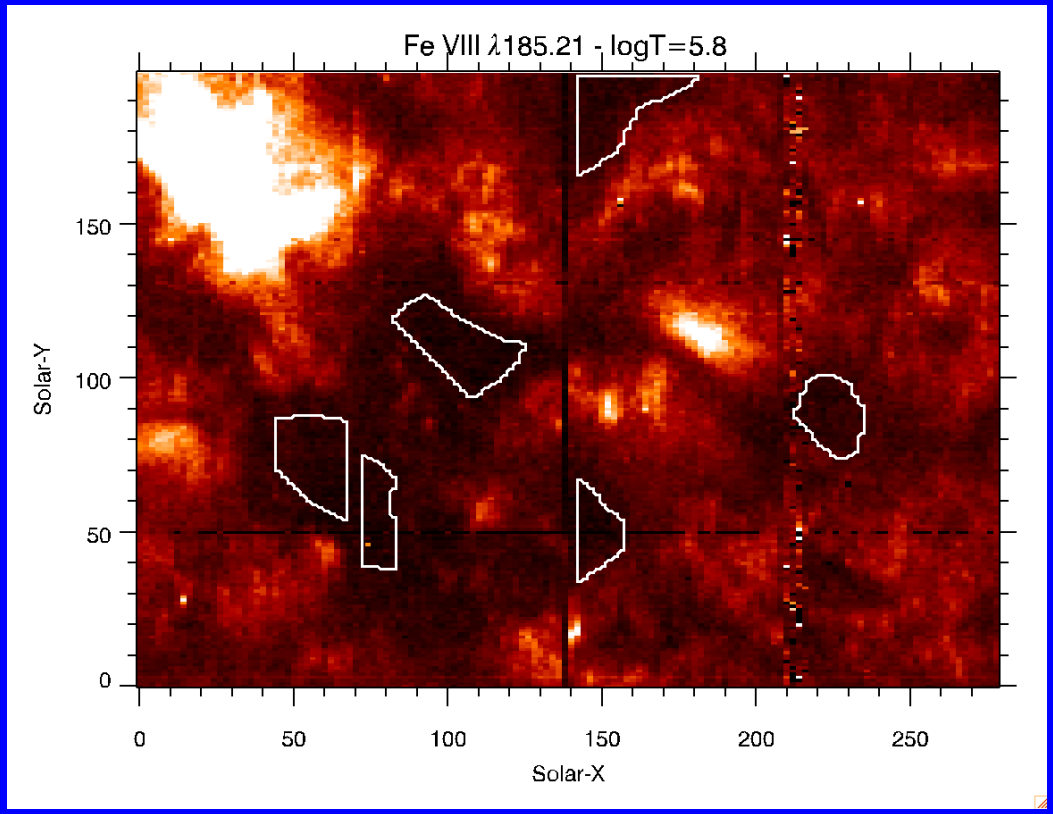
Example coronal hole – 11 July 2008

- EIS monochromatic raster images



Coronal hole selection

- Six dark coronal hole areas identified in Fe VIII λ185.21 image
- Spatial pixels summed to yield six coronal hole spectra

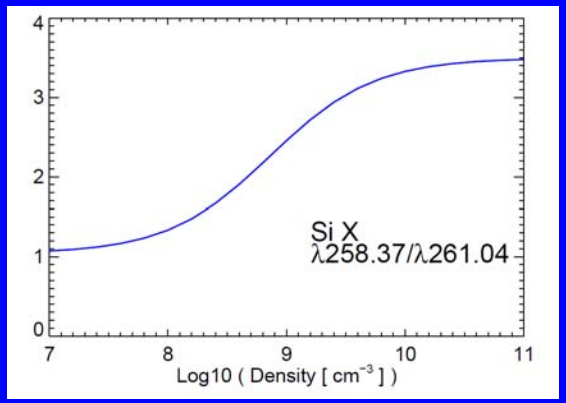


Hinode / EIS

EIS coronal hole density diagnostics

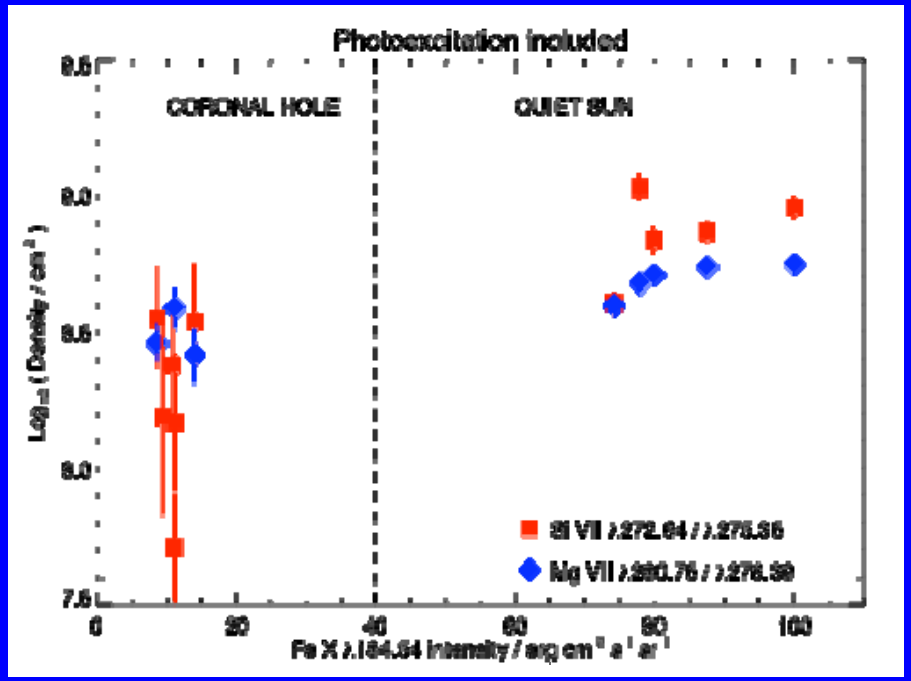
Ion	Ratio	Log (*T* / K)	Photoexc.?
Mg VII	λ280.75 / λ278.39	5.8	No
Si VII	λ272.64 / λ275.35	5.8	Yes
Fe VIII	λ186.60 / λ185.21	5.8	Yes
Fe X	λ257.26 / λ184.54	6.0	No
Si X	λ258.37 / λ261.04	6.1	Yes
Fe XII	λ186.88 / λ195.12	6.1	No

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



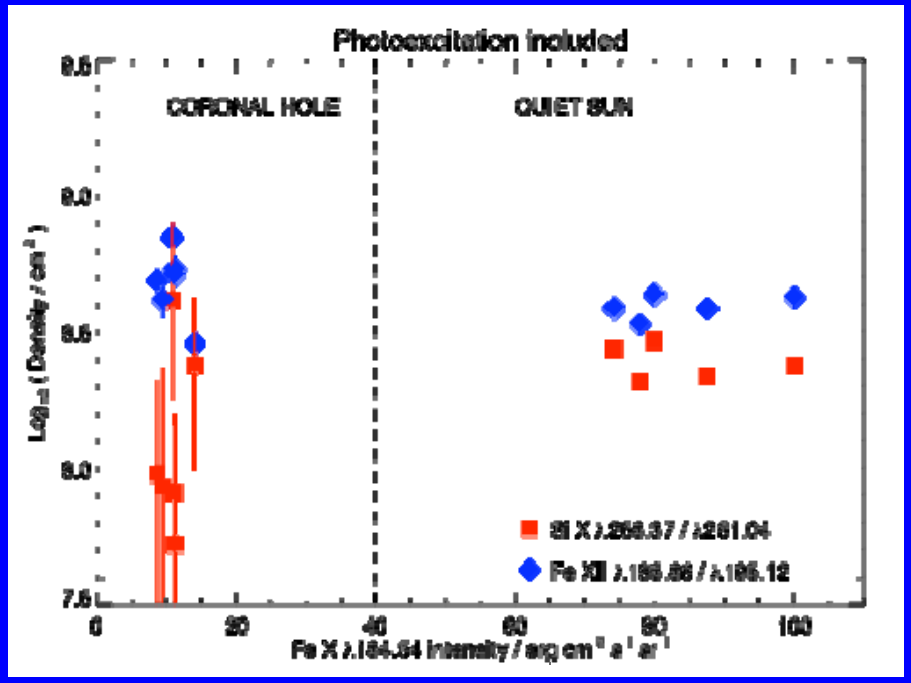
Ion	CH Dens	QS Dens	CH Pressure	QS Pressure
Si VII	8.26	8.86	14.06	14.66
Mg VII	(8.58)	8.78	(14.38)	14.58

(Log_{10} values)

Hinode / EIS

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

- Si X is sensitive to photoexcitation



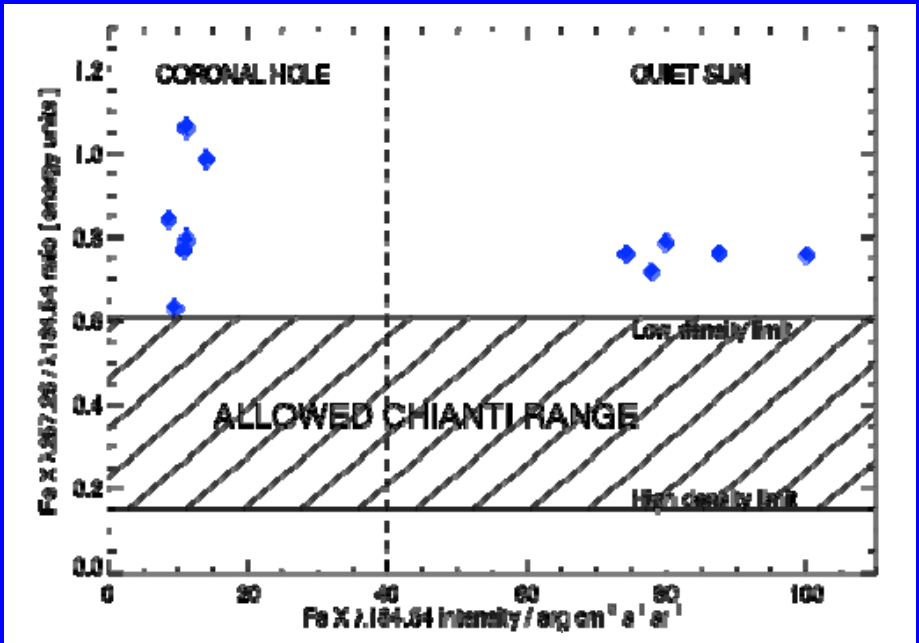
Ion	CH Dens	QS Dens	CH Pressure	QS Pressure
Si X	8.17	8.39	14.27	14.49
Fe XII	8.67	8.58	14.77	14.68

(Log_{10} values)

Hinode / EIS

Fe X λ184.54 /λ257.26

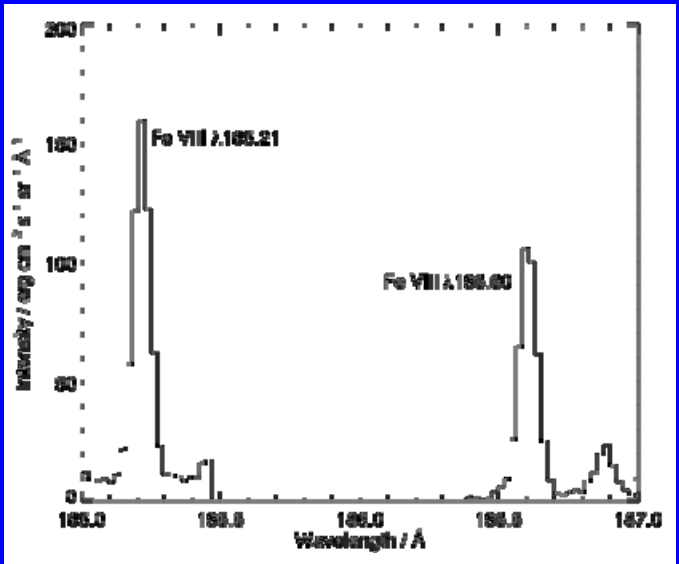
- In both quiet Sun and coronal holes the measured Fe X ratios are *above* the low density limit
- The coronal hole values are higher than the quiet Sun values
- Implies ratio is diagnosing density differences…
- …*but*, measurements inconsistent with atomic theory

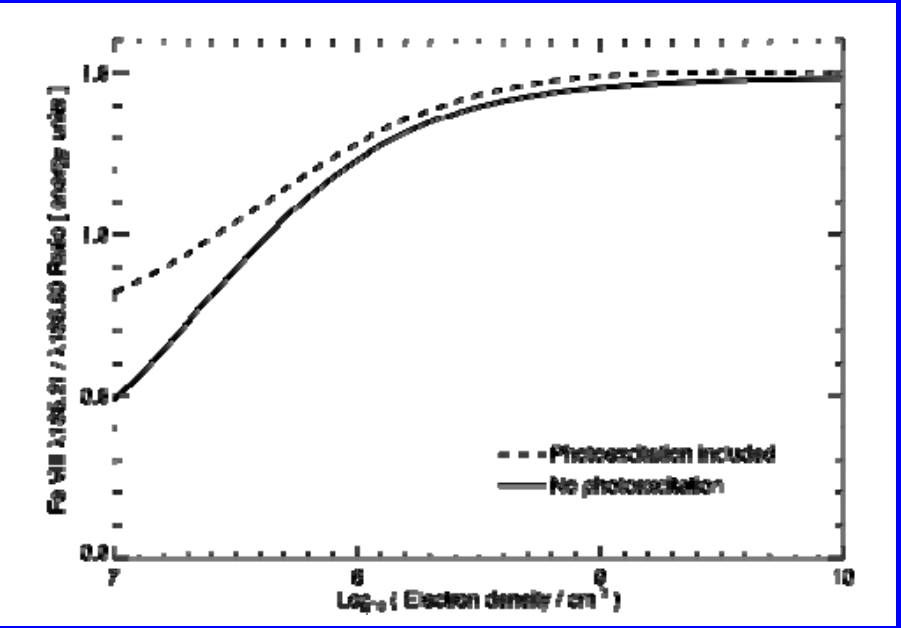


Hinode / EIS

Fe VIII λ185.21 / λ186.60

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

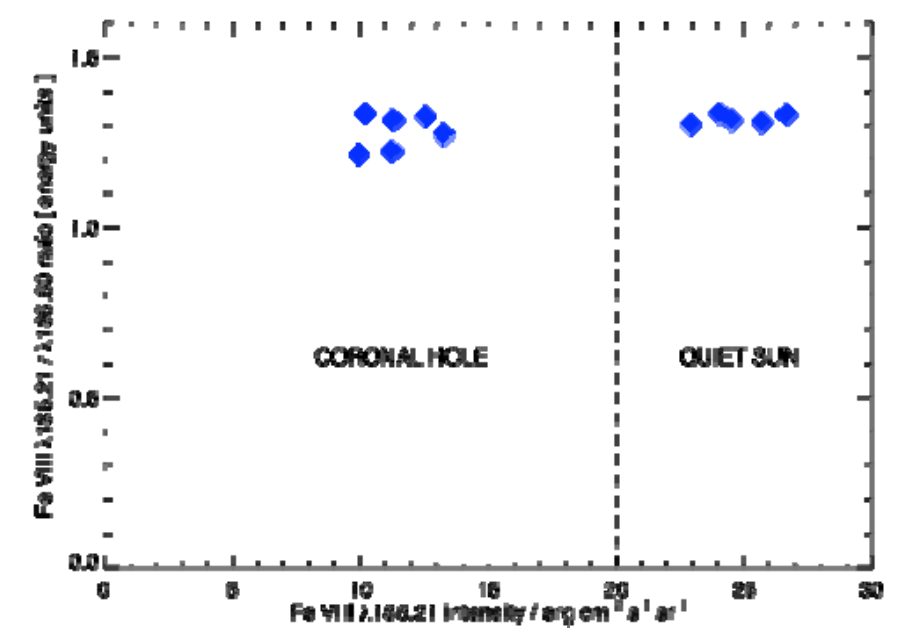




Hinode / EIS

Fe VIII λ185.21 / λ186.60

- 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

Hinode / EIS

Conclusions

- No evidence is found for the very low densities found by Young & Esser (1999a,b)

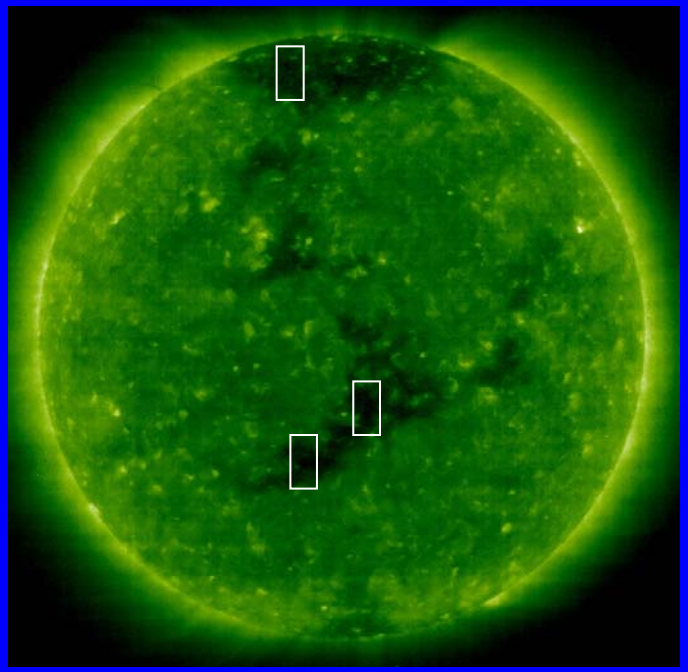
- Different ions show inconsistent results
  - Si VII, Mg VII, Si X show lower CH densities by 0.2-0.6 dex compared to QS
  - Fe VIII & Fe XII show same density in CH and QS
  - Fe X measurements inconsistent with theory

- Further work
  - need to investigate 'deep-cleaning' of CCD warm pixels
  - update atomic data (Si VII, Si X, Fe X)

Hinode / EIS

Note for EIS Chief Observers

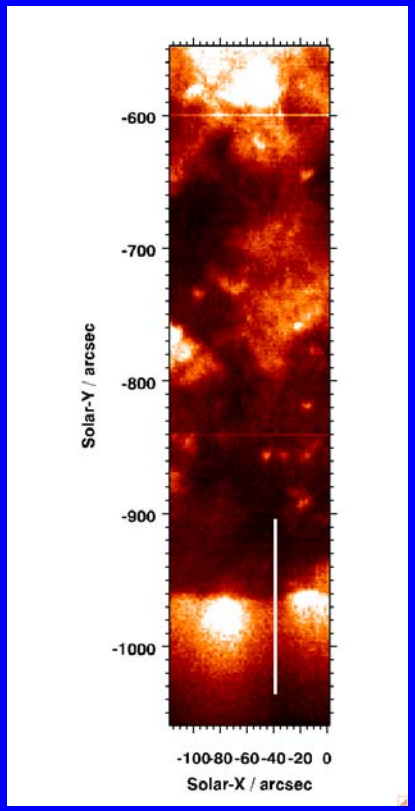
- Please run my study PRY_CH_density if you see a nice coronal hole!
- Low data volume study optimised for S-band operations

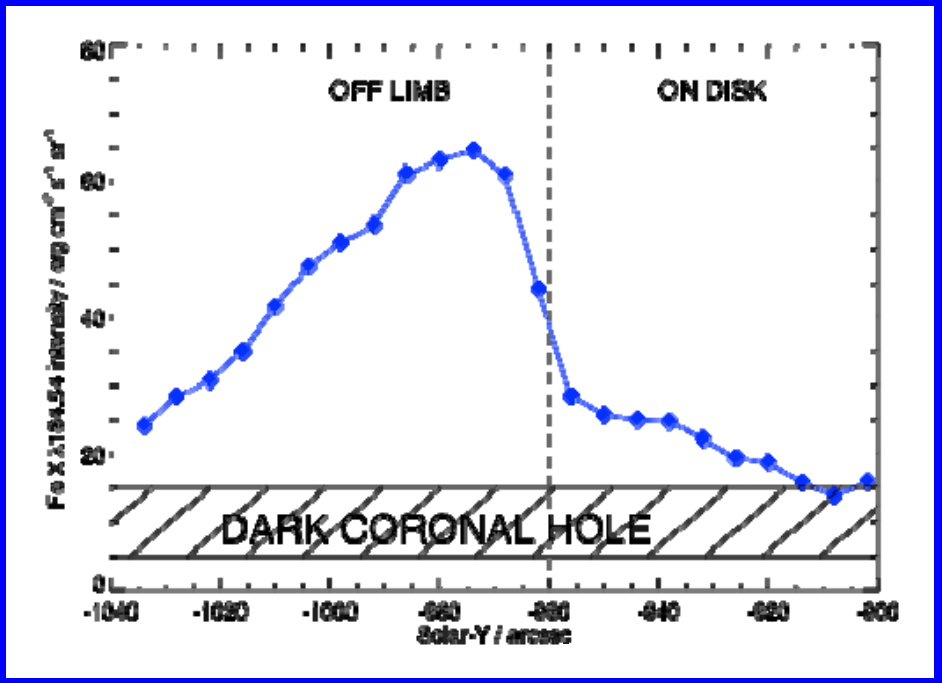


Hinode / EIS

Off-limb vs. on disk

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

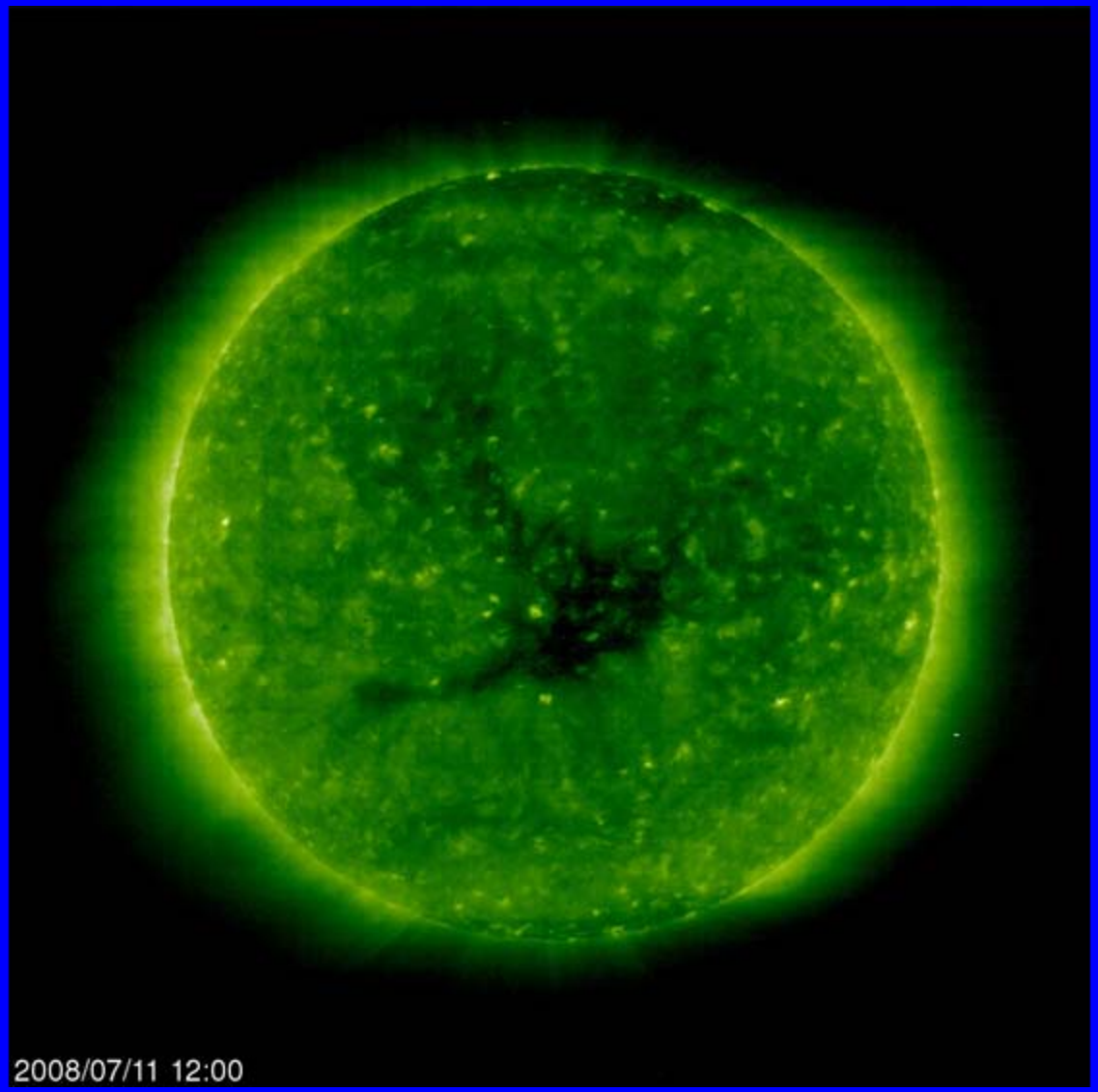




Fe X λ184.54, 19-Jan-08, 13:35

Hinode / EIS

Coronal holes



SOHO/EIT
Fe XII 195

Hinode / EIS