UNIVERSITY OF CAMBRIDGE

Solar Spectroscopic Diagnostics: A Long and Winding Road

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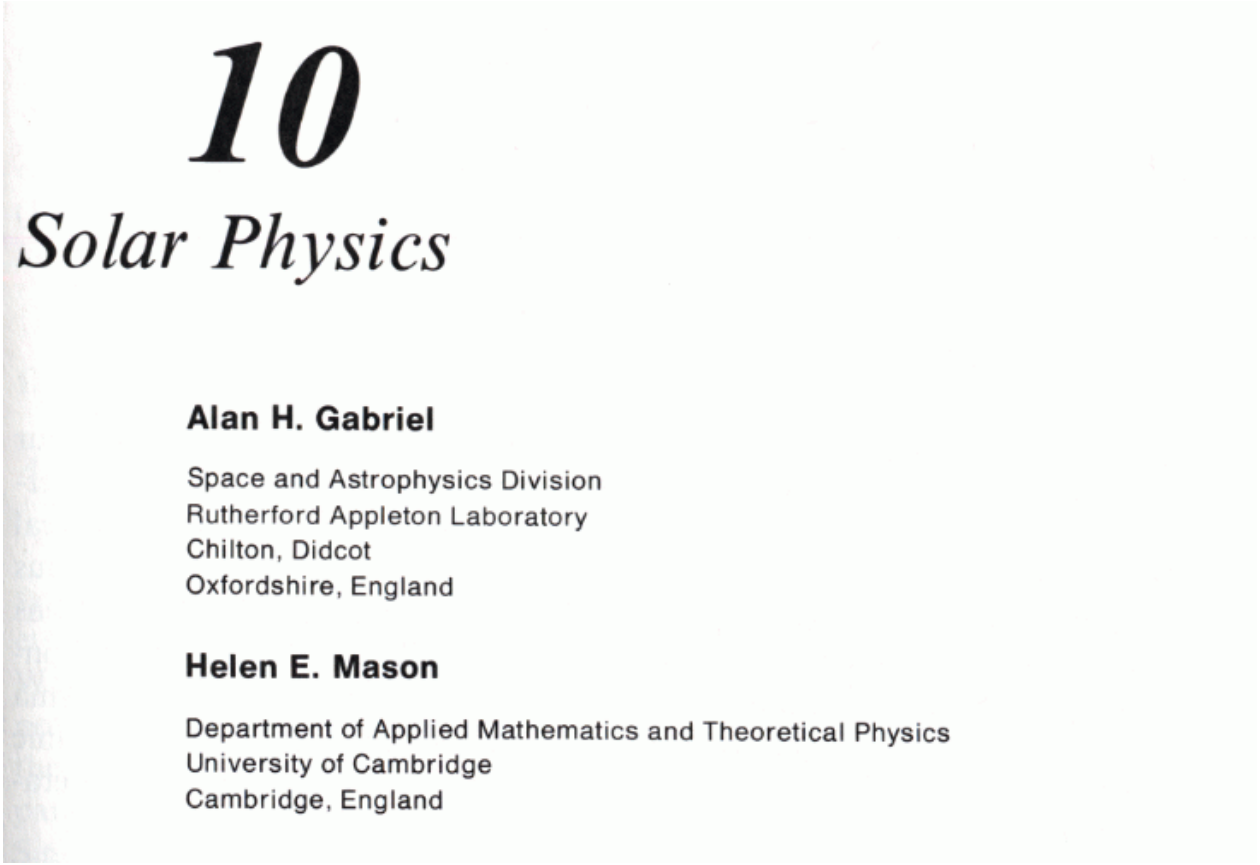
(with thanks to Giulio Del Zanna; CHIANTI team, UK APAP team; CDS, SUMER and Hinode teams)

IAS, Orsay, June 20th 2013

Where to start?

Applied Atomic Collision Physics, 1982
Vol 1, Eds H.S.W. Massey and D.R. Bates



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Solar Physics

Alan H. Gabriel

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Oxfordshire, England

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University of Cambridge
Cambridge, England

A much neglected review paper
(in a rather obscure book)!!

The Structure of the Solar Atmosphere?

Gabriel and Mason, 1982

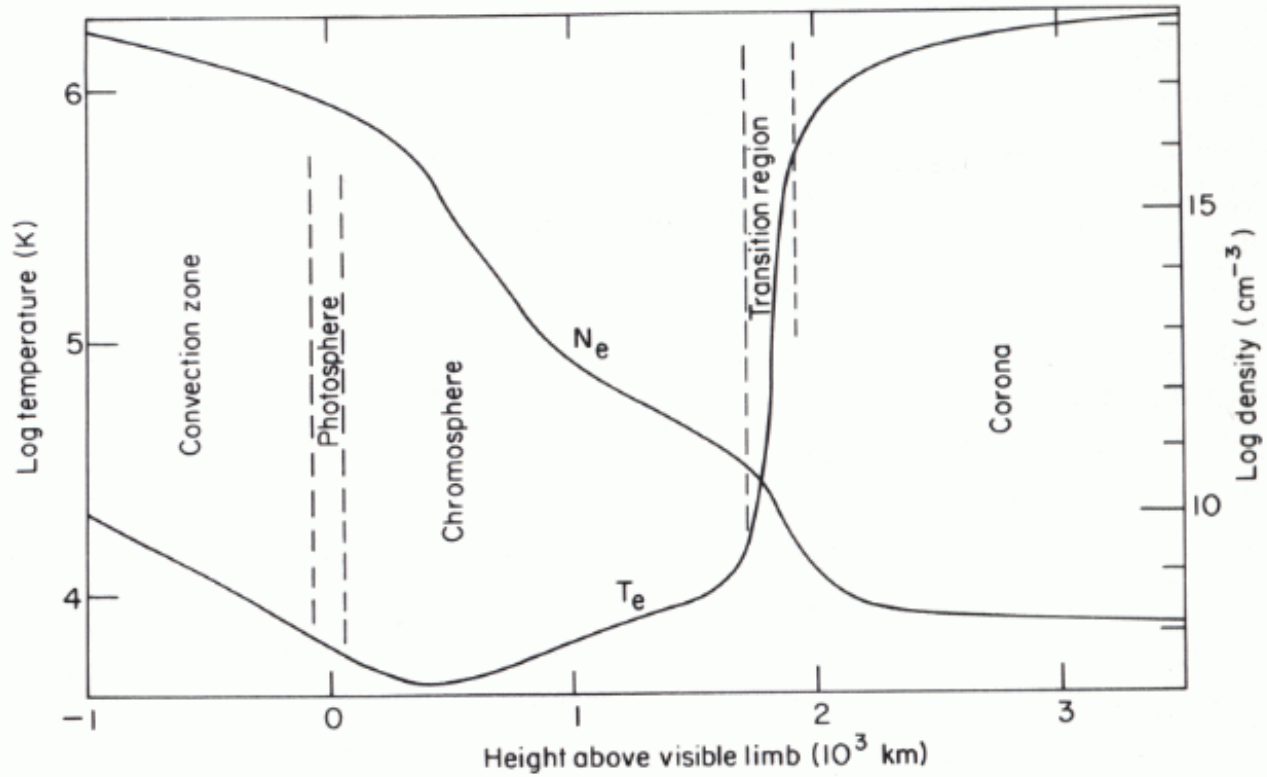


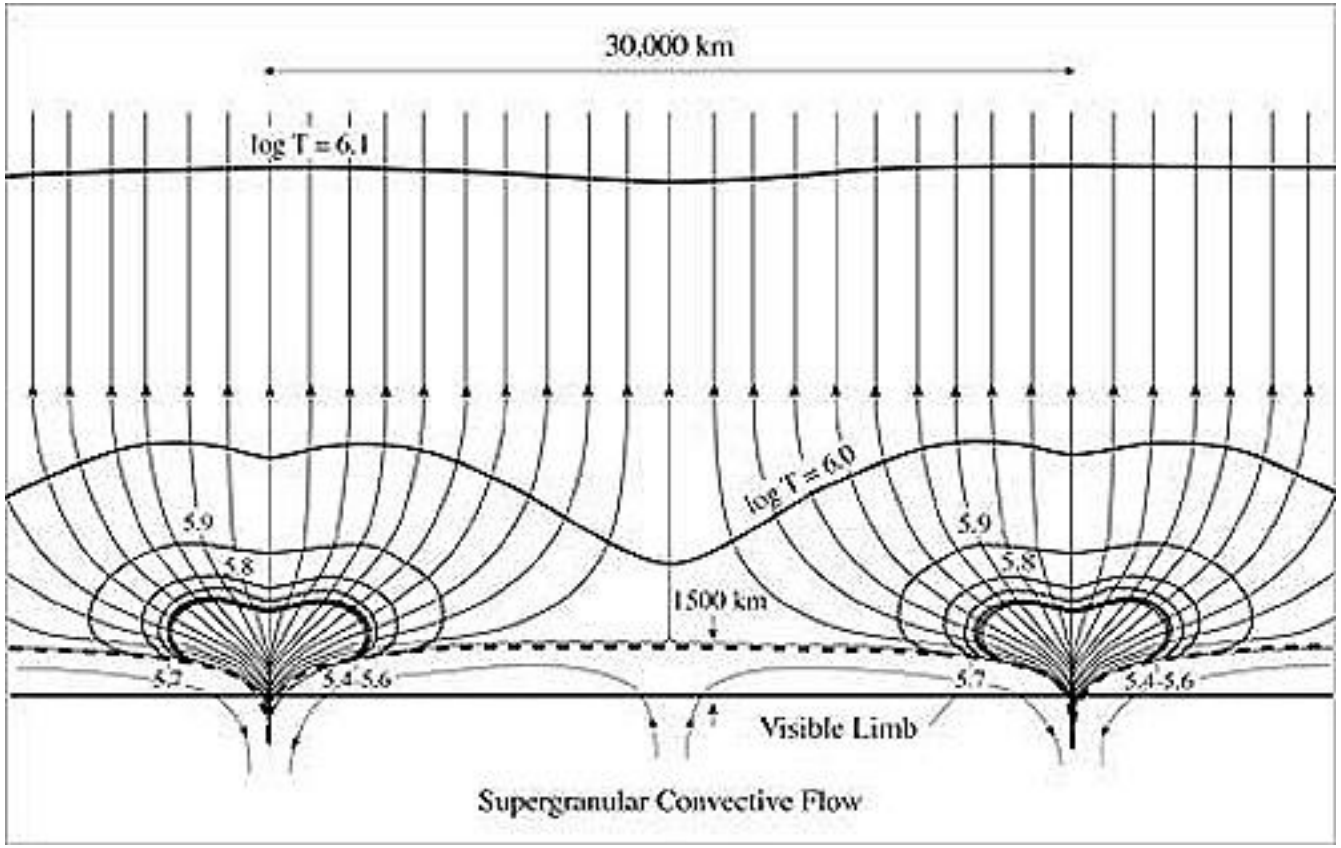
Fig. 1. Schematic representation of the variation with height of the mean values of temperature and density in the outer layers of the sun.

Not really, but maybe we should have charged folk who used this figure? By now, we would have been millionaires...

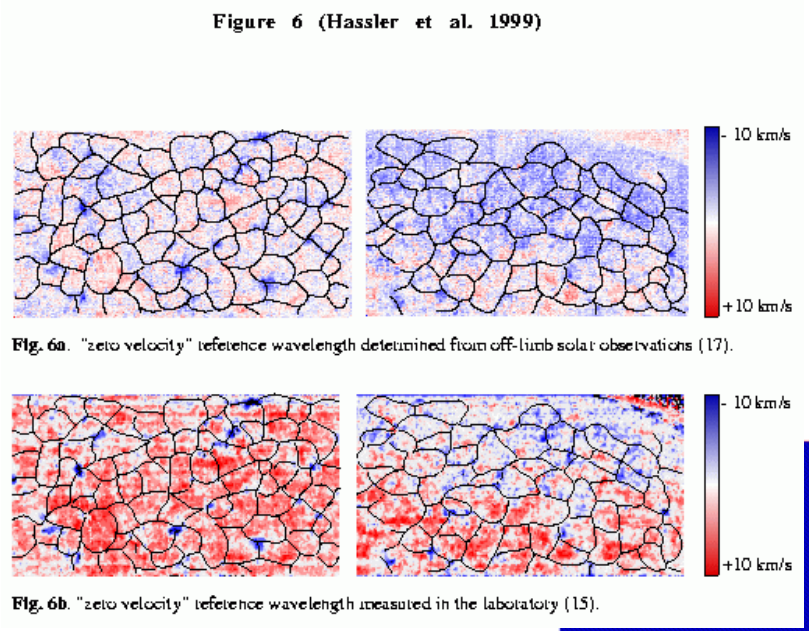
Solar Transition Region

Actually, I think Alan should have charged folk to use this figure: Gabriel, A.H., 1976, *A magnetic model of the Solar Transition Region*, Phil. Trans of the Royal Society of London, 281, 1304, Fig 5

He would be a millionaire!

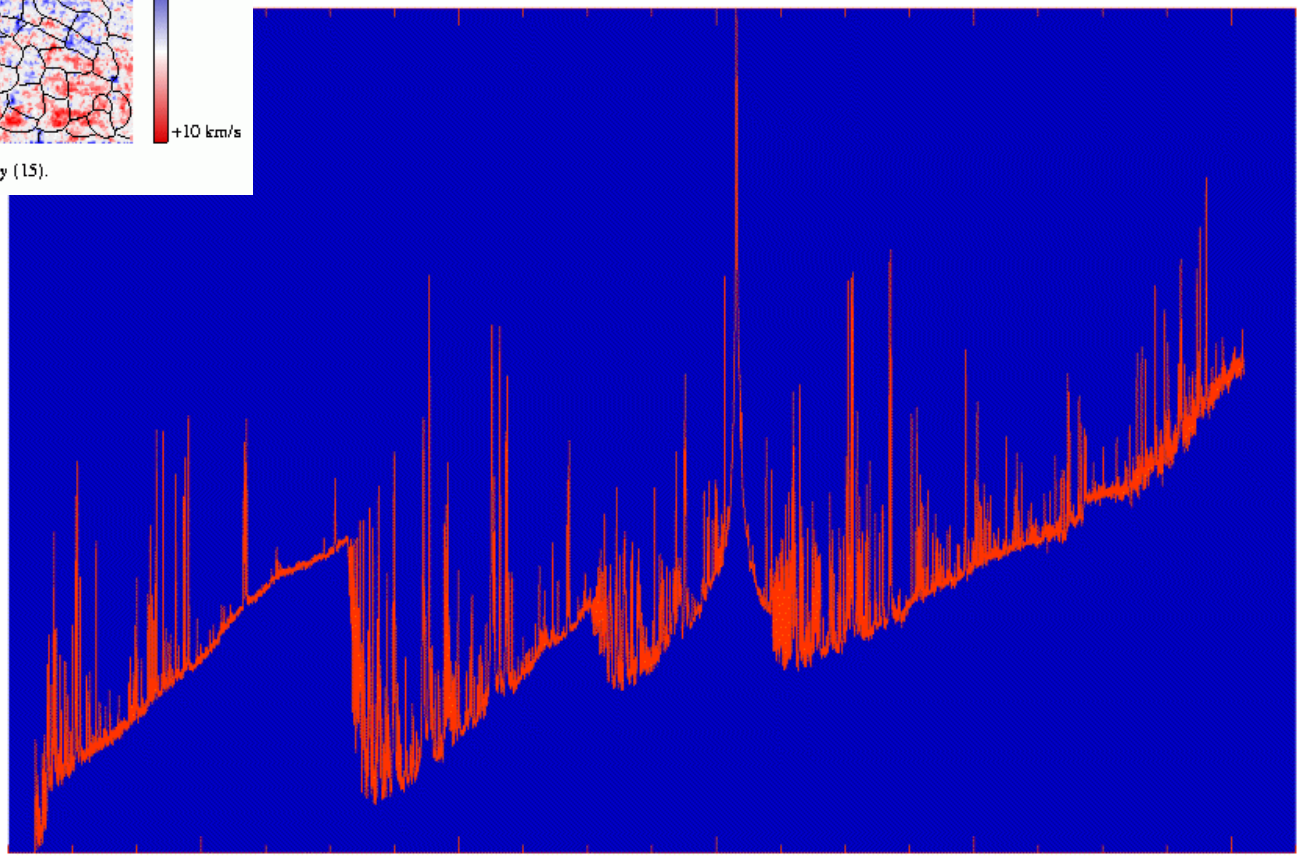


SUMER – Lemaire et al (MEDOC)



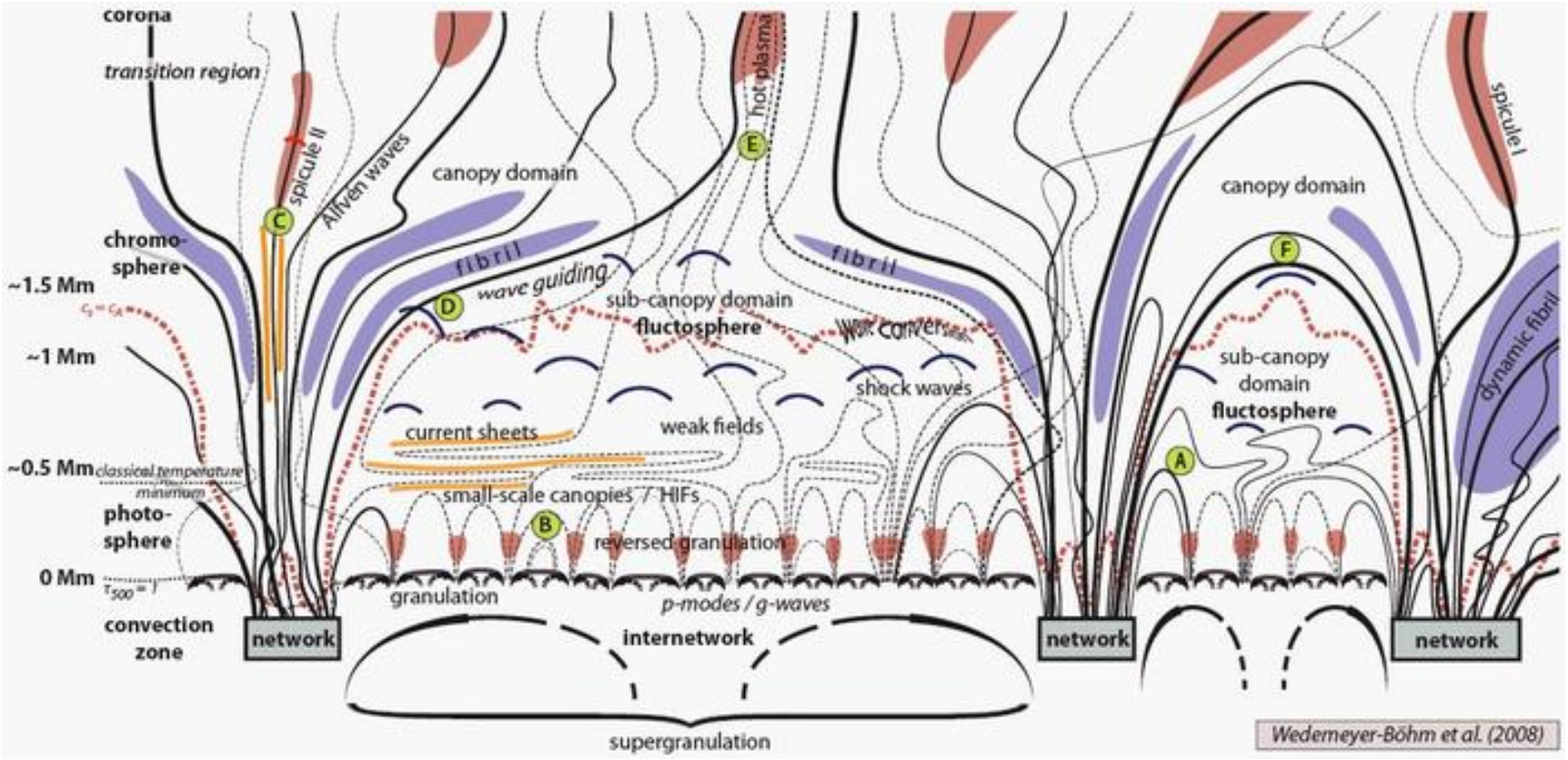
TR diagnostics
Flows
Line widths
Electron Density
Temperature

David et al, 1998, Temp gradient in a solar coronal hole. (OVI, CDS+SUMER)



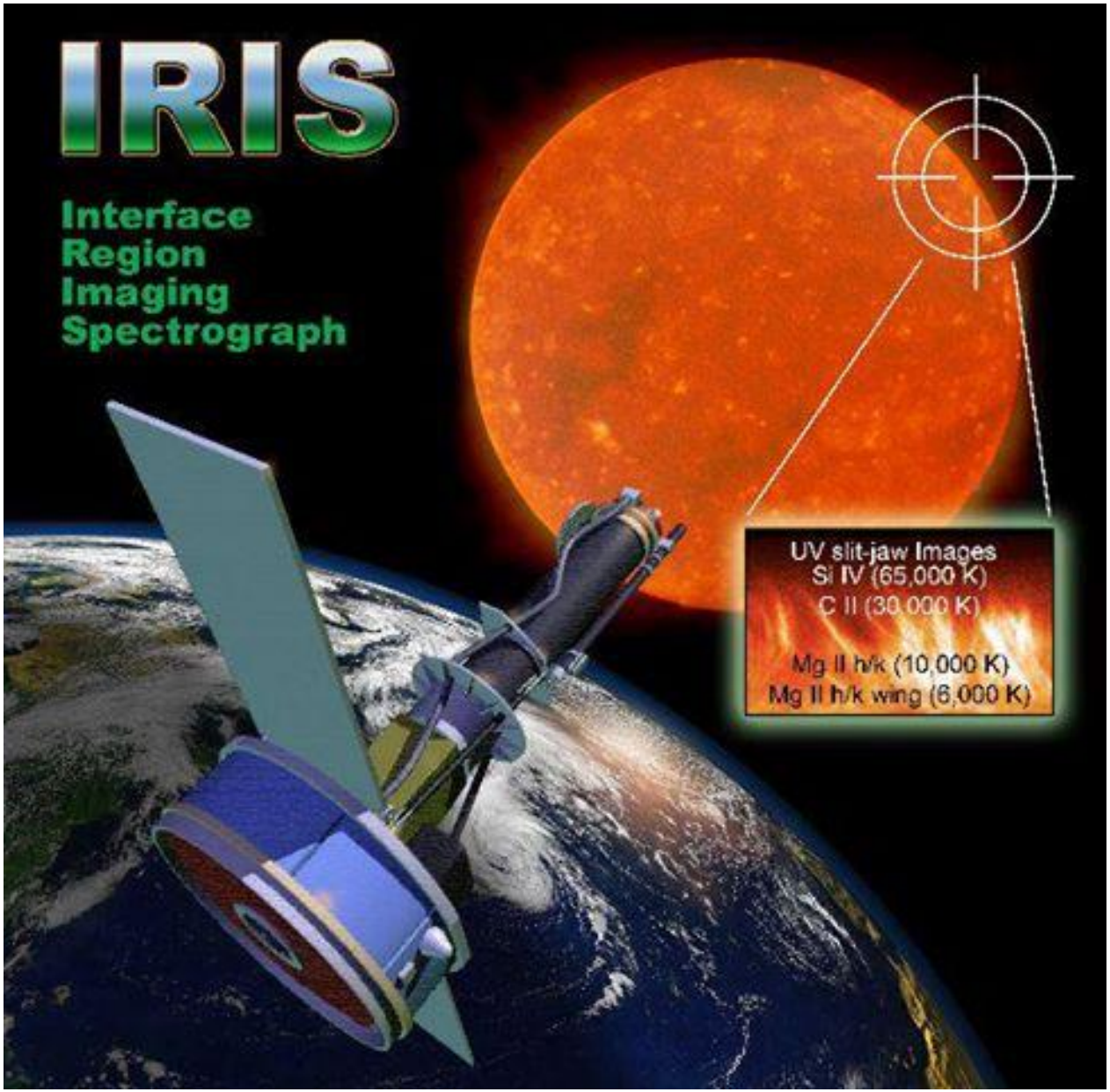
Things are now a little more complicated!

But, do we understand the TR any better?

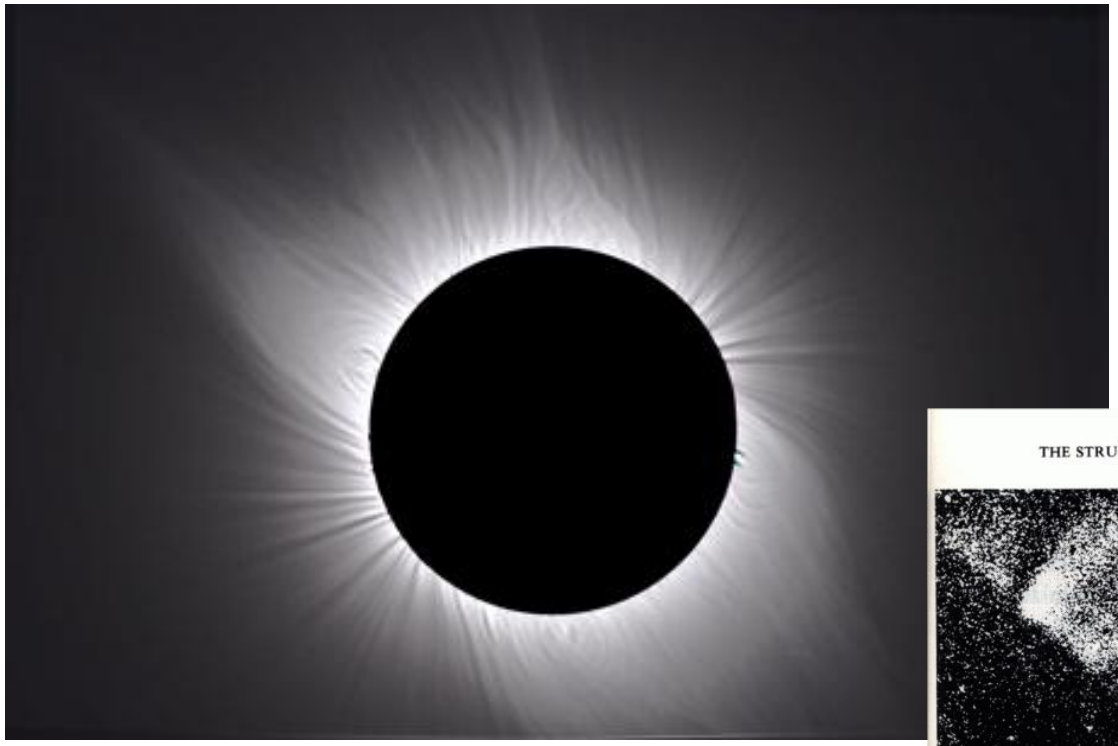


The Wedemeyer-Bohm cartoon representing the known or suspected ("fluctosphere"?) constituents of the interface zone.

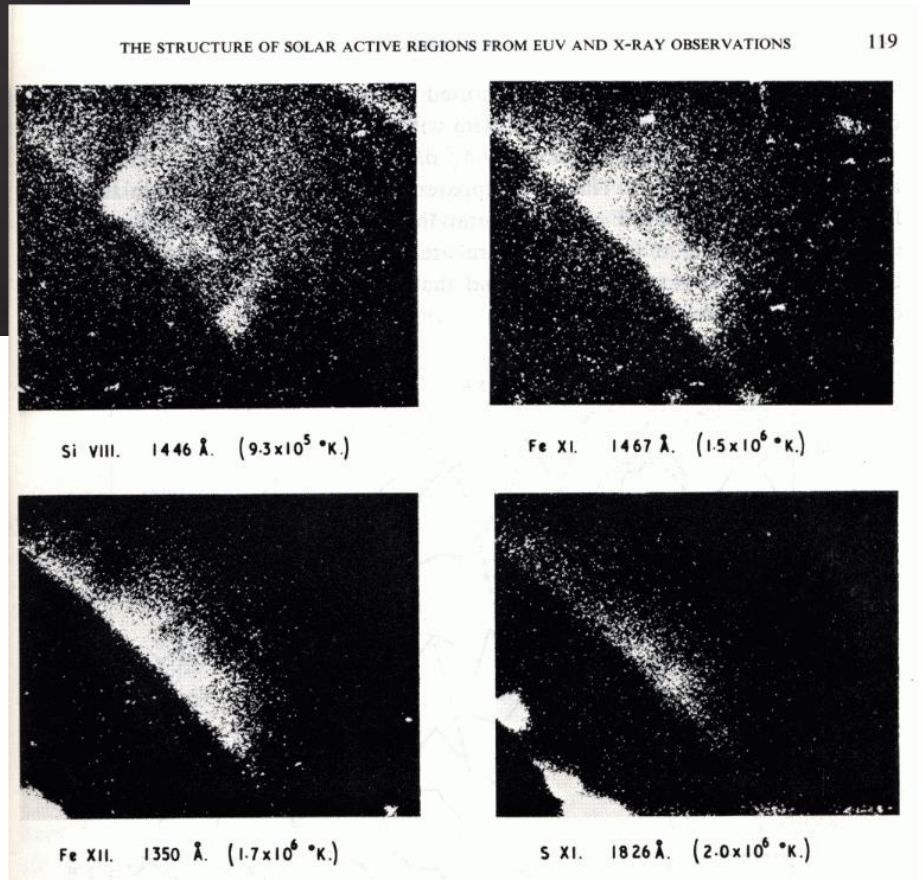
Will IRIS be able to solve the mysteries of the TR?



The Solar Corona: Eclipse Observations



Gabriel et al, 1971
Coronal forbidden lines

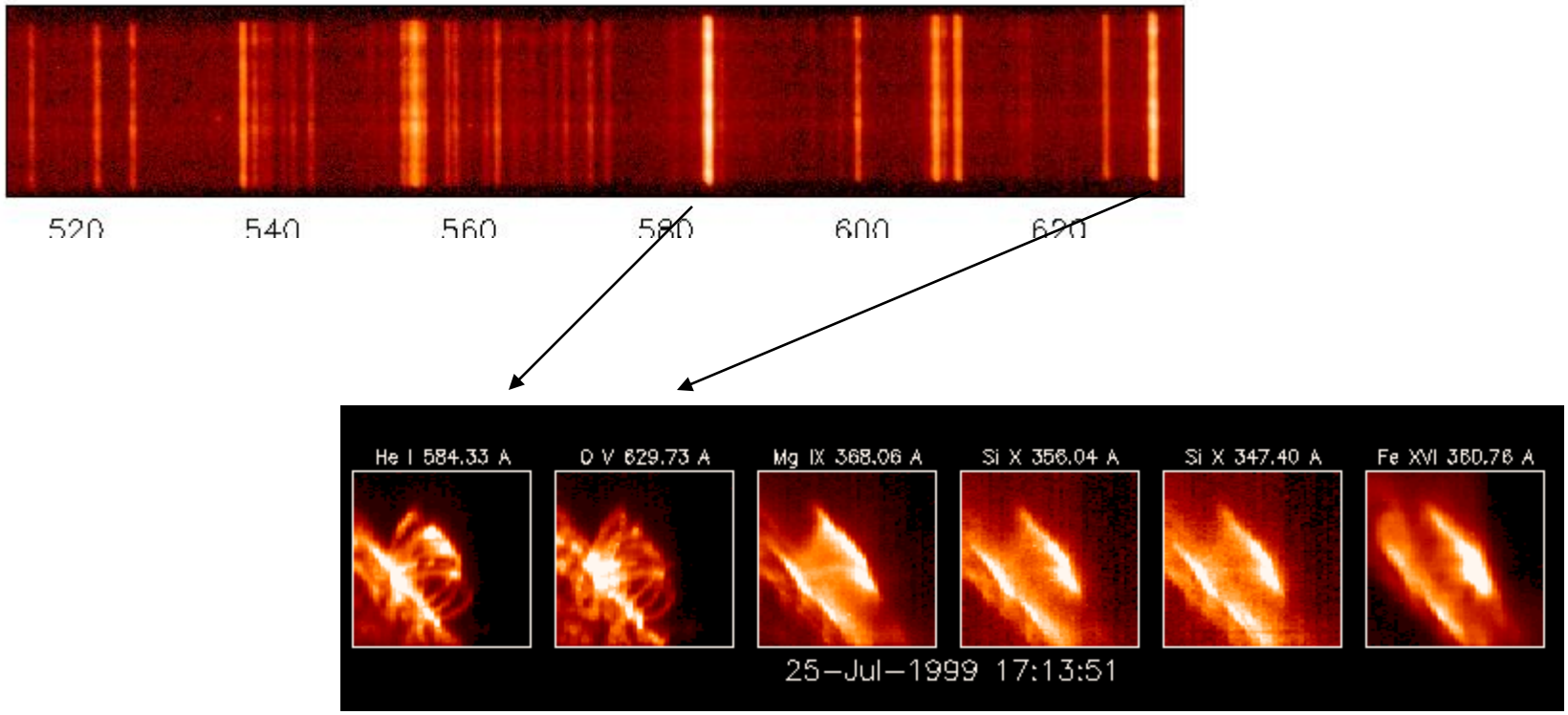


SOHO – CDS

Coronal Diagnostic Spectrometer

PI group – Rutherford Appleton Laboratory, UK

provides spectra and images



Electron Density Diagnostics

Gabriel and Mason, 1982

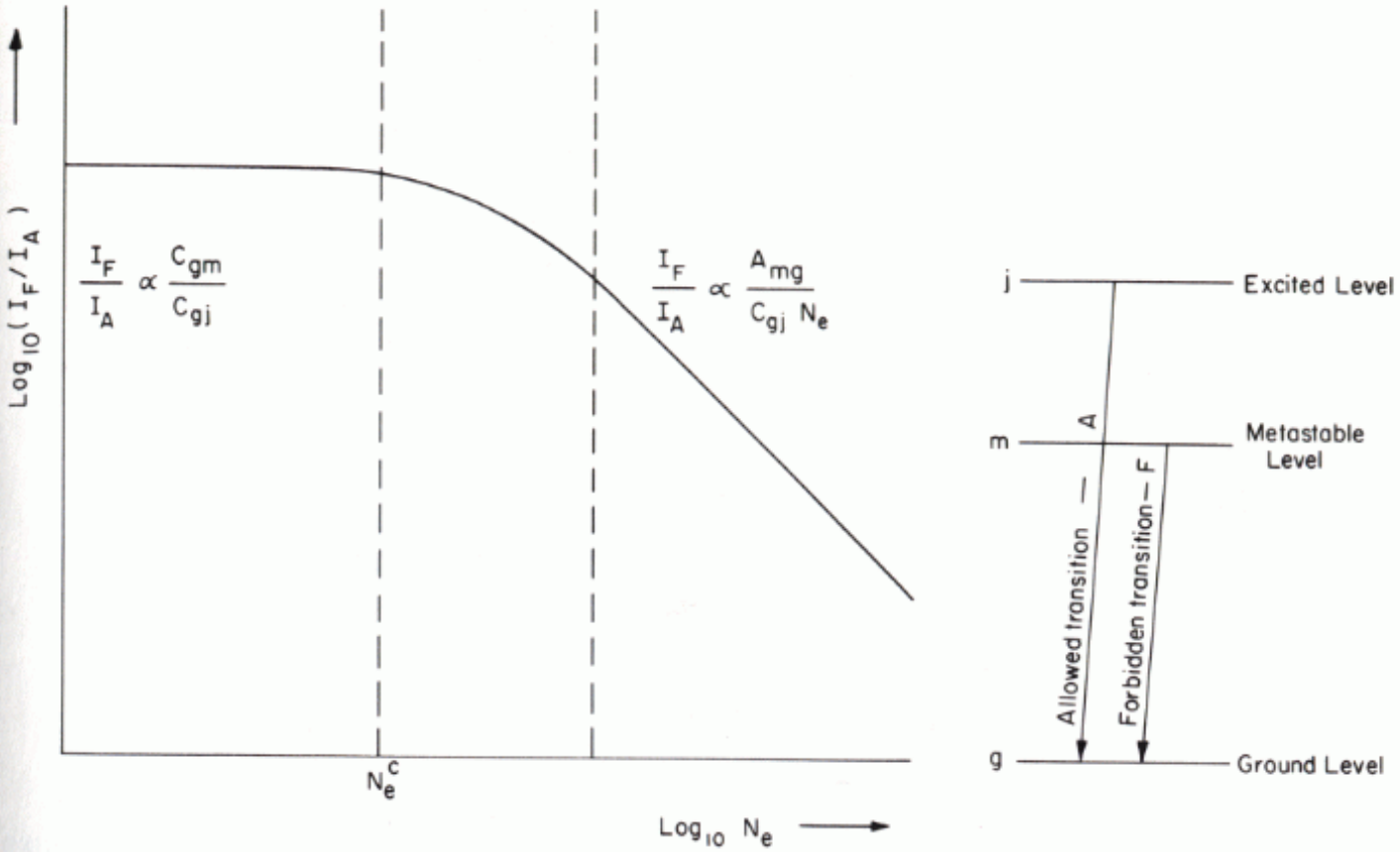
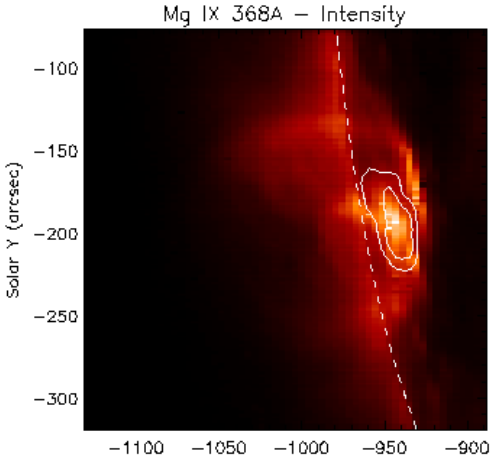
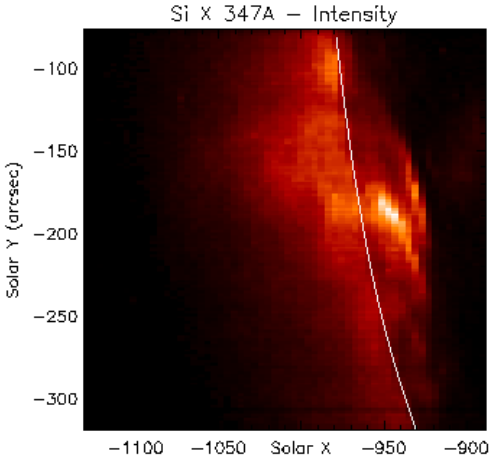


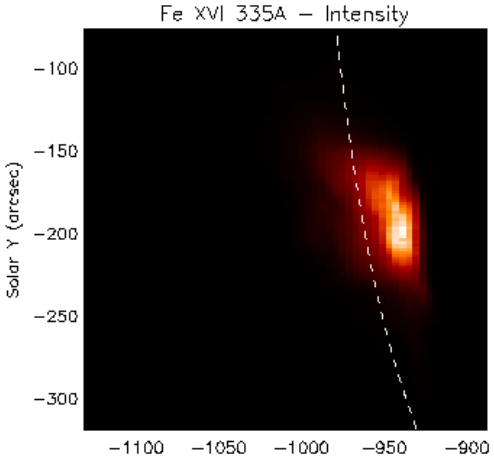
Fig. 3. The variation with density of the intensity ratio of a forbidden to an allowed transition.

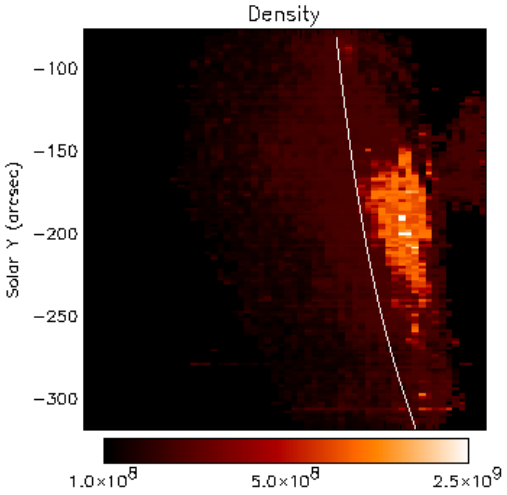
SoHO/CDS

Electron Density and Temperature Structure of a limb active region - *Mason et al, 1999*





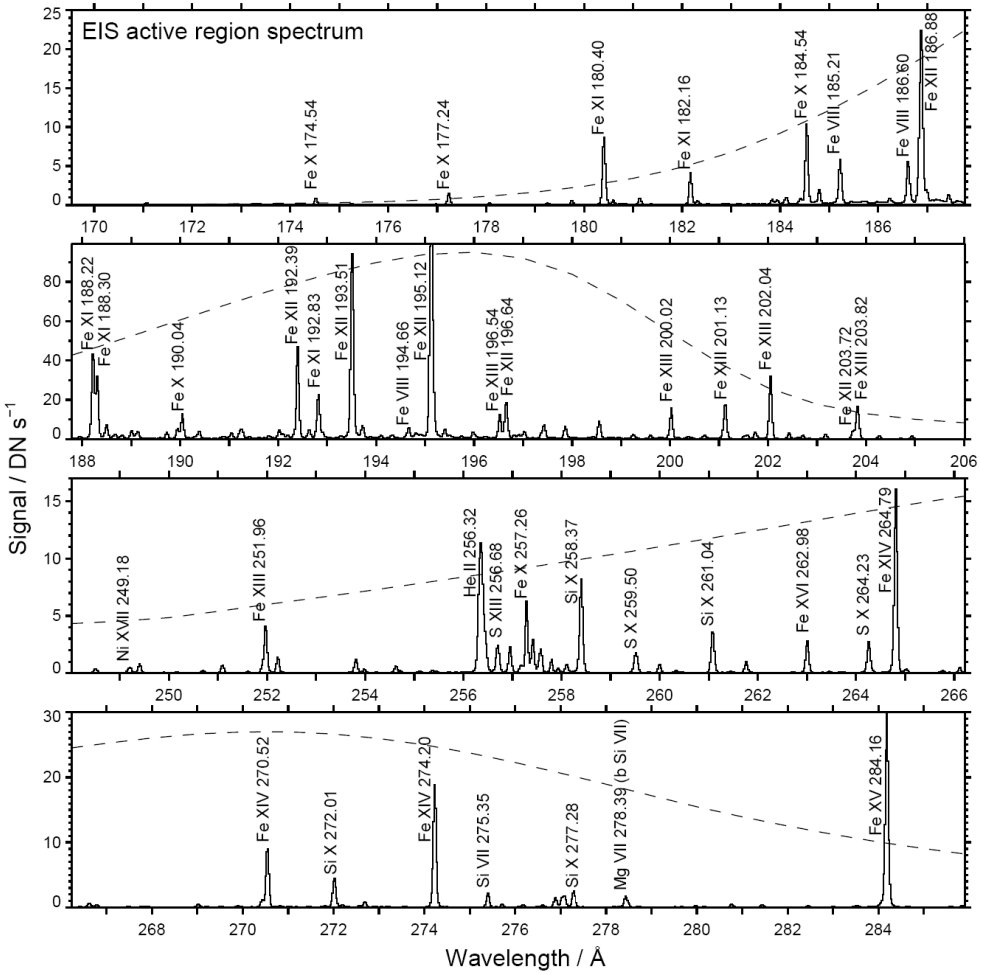




Hinode/EIS spectrum

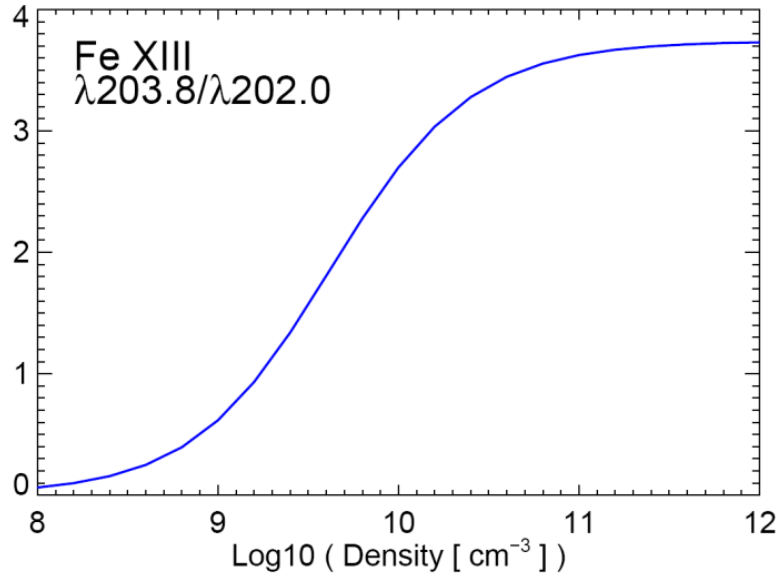
- **Hinode/EIS spectra are dominated by coronal ions (iron, particularly)**

Young, Mason et al. (2007, PASJ)

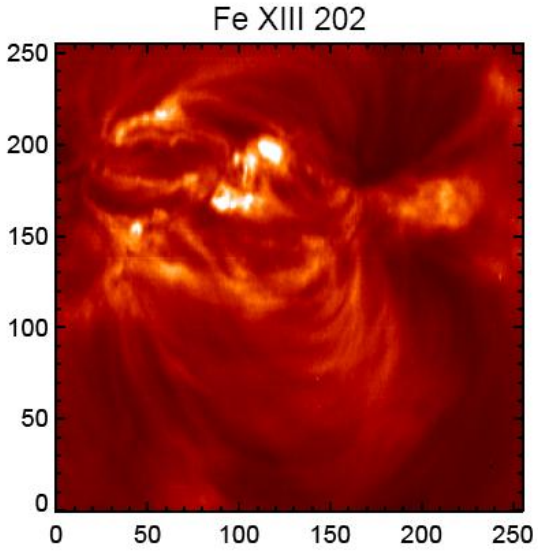


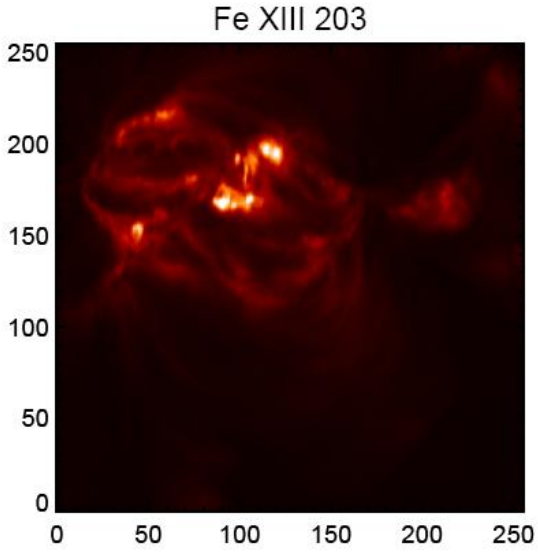
Active region density map

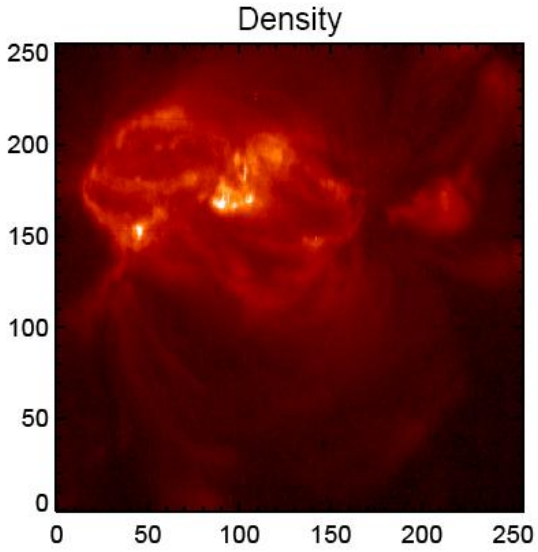
Peter Young, 2007



The high quality of the EIS data makes density maps relatively easy to generate



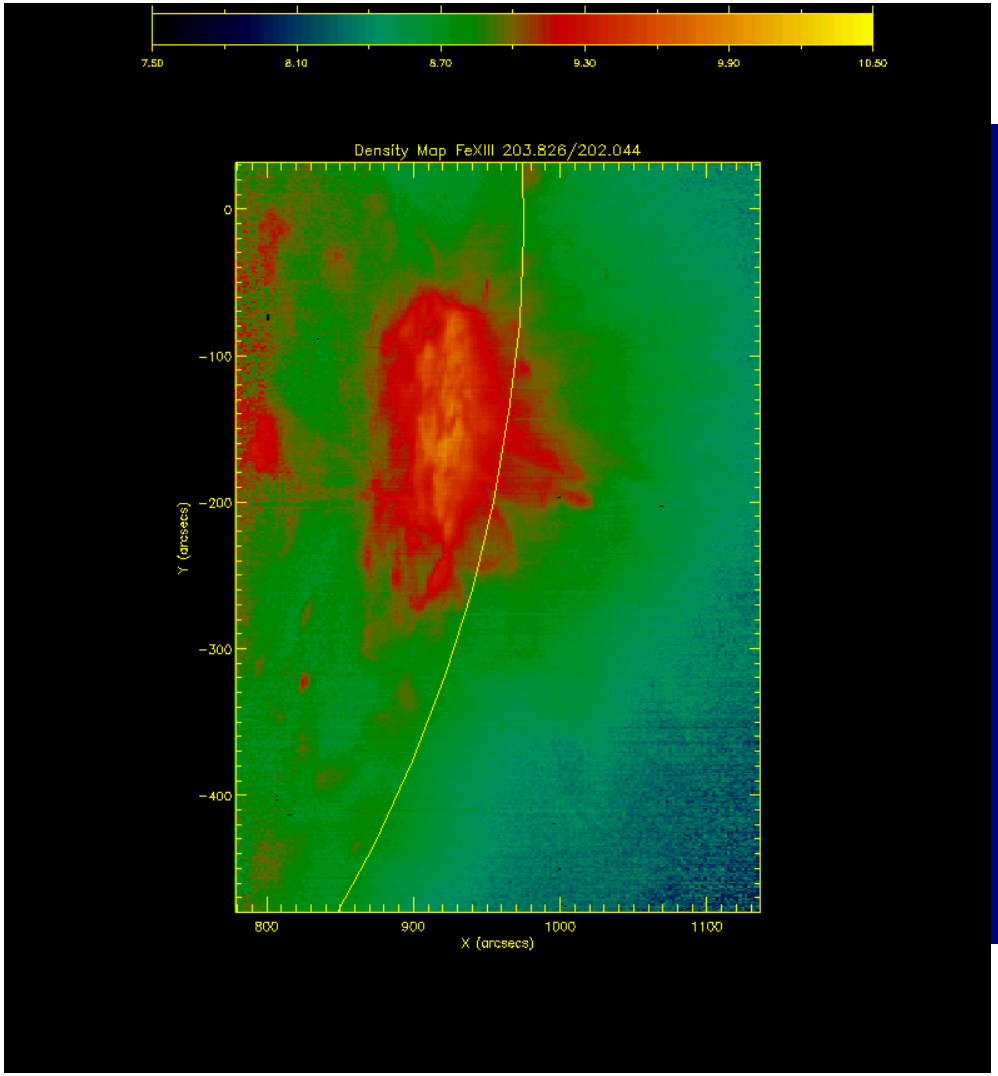




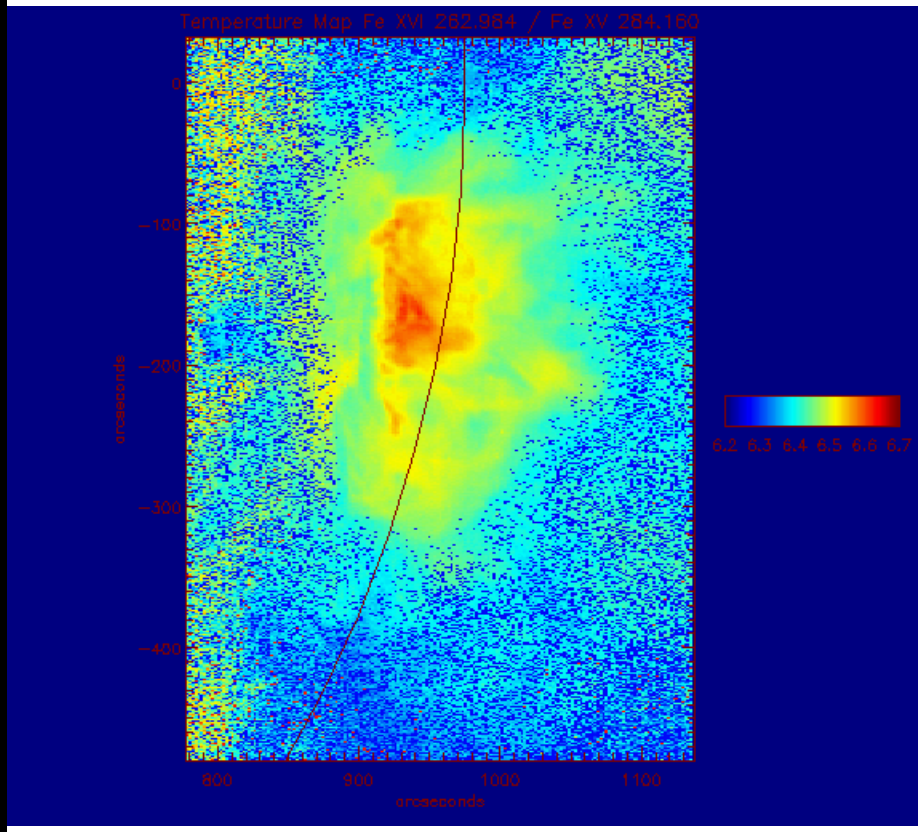
Hinode EIS - temperature and density map for a limb AR

O'Dwyer et al, 2011

Average electron density map from FeXIII lines



Temperature map from FeXVI/FeXV
Red is Log T = 6.7, yellow is Log T= 6.5



Hot, dense AR cores are clearly seen with EIS. XRT shows 'dynamic' activity.

Differential Emission Measure

Gabriel and Mason, 1982

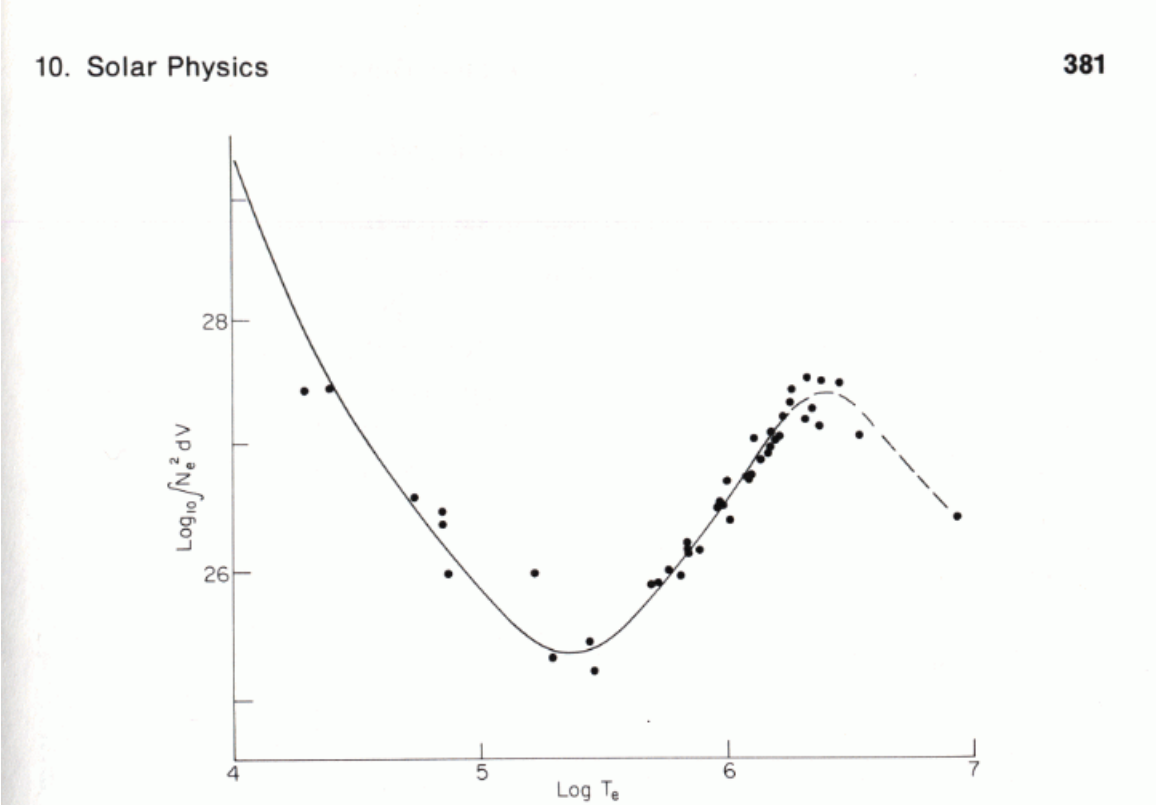
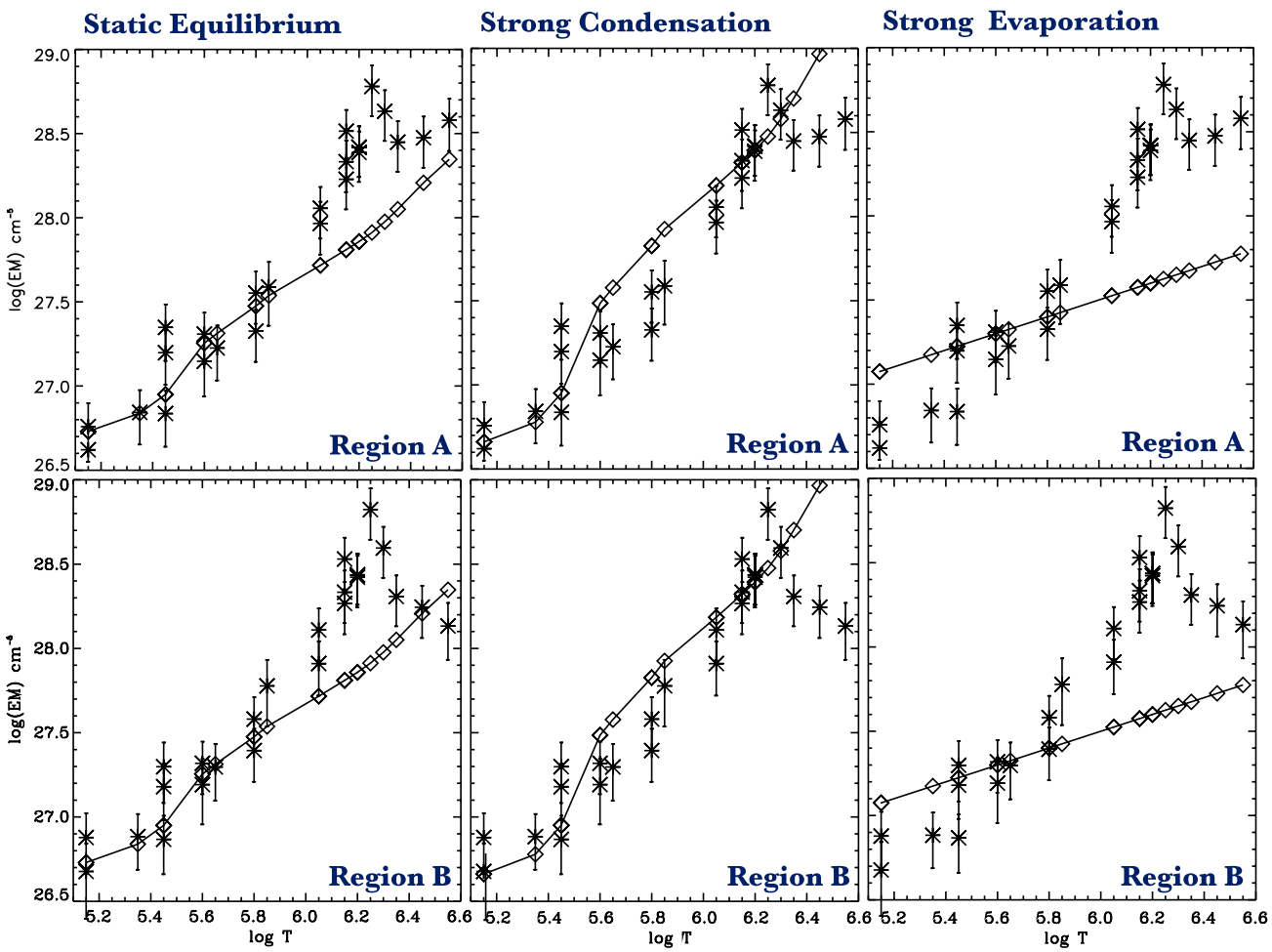


Fig. 10. A differential emission measure curve for the mean quiet solar atmosphere, derived from observation of absolute spectral intensities (Gabriel, 1977a).

- *Why measure astrophysical X-ray spectra?*
  A.H. Gabriel, 1977, Letter to Nature, 267, 410
- *Transition Region Dynamical Components*
  R. Ben El Hadj, A.H. Gabriel, F. Bely-Dubau, ESA SP-505

Observed vs Theoretical EM(T) for the moss

Tripathi, Mason and Klimchuk, 2010



Static Equilibrium

$EM_{se} \propto P\, \Lambda(T)^{-1/2}\, T^{3/4}$

Strong Condensation

$EM_{con} \propto J\, \Lambda(T)^{-1}\, T$

Strong Evaporation

$EM_{ev} \propto P^2\, J^{-1}\, T^{1/2}$,

P = pressure

J = mass flux

Λ(T) = rad. loss fctn.

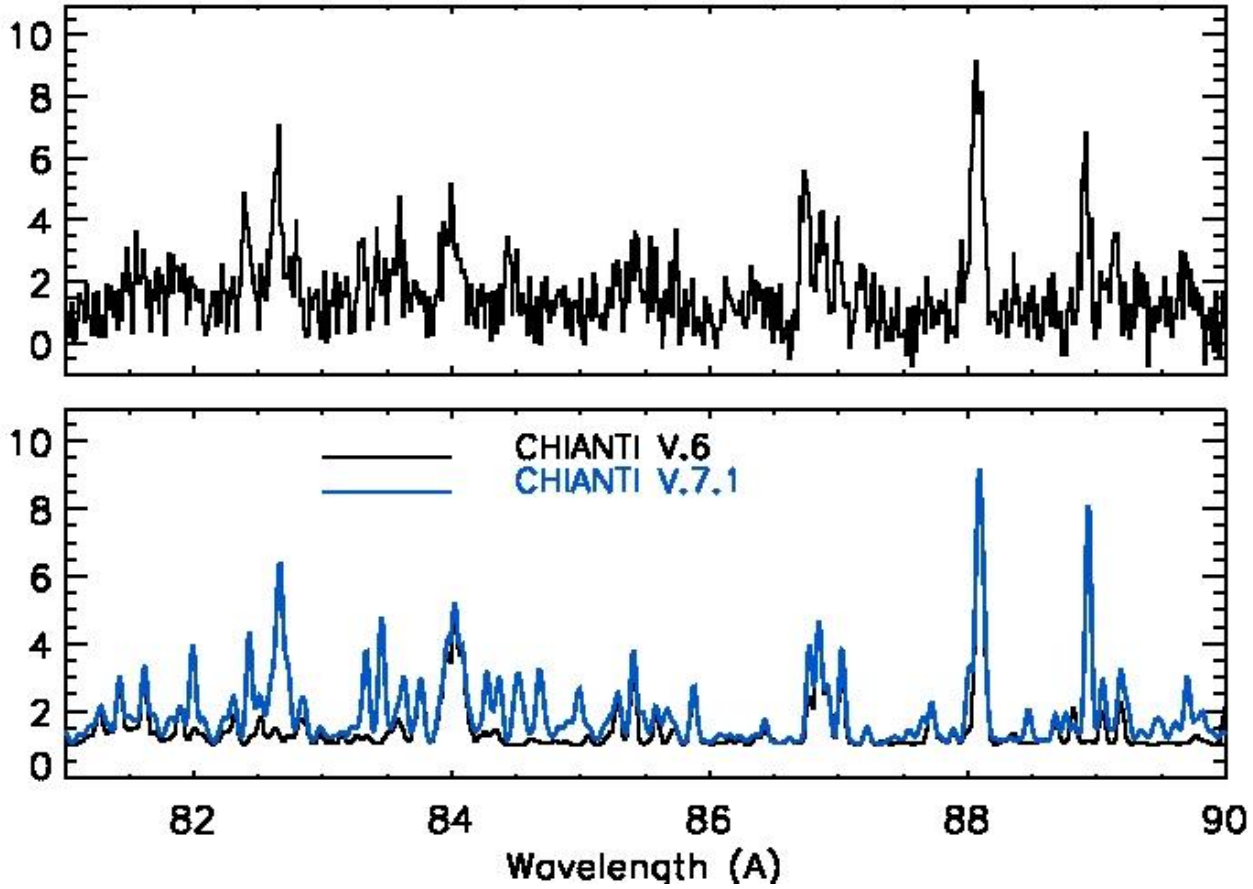
EM for strong condensation best reproduce the observations supporting the idea that hot loops seen in the core of active regions are **heated by nanoflares i.e.** impulsive heating.

CHIANTI

An atomic database for astrophysics

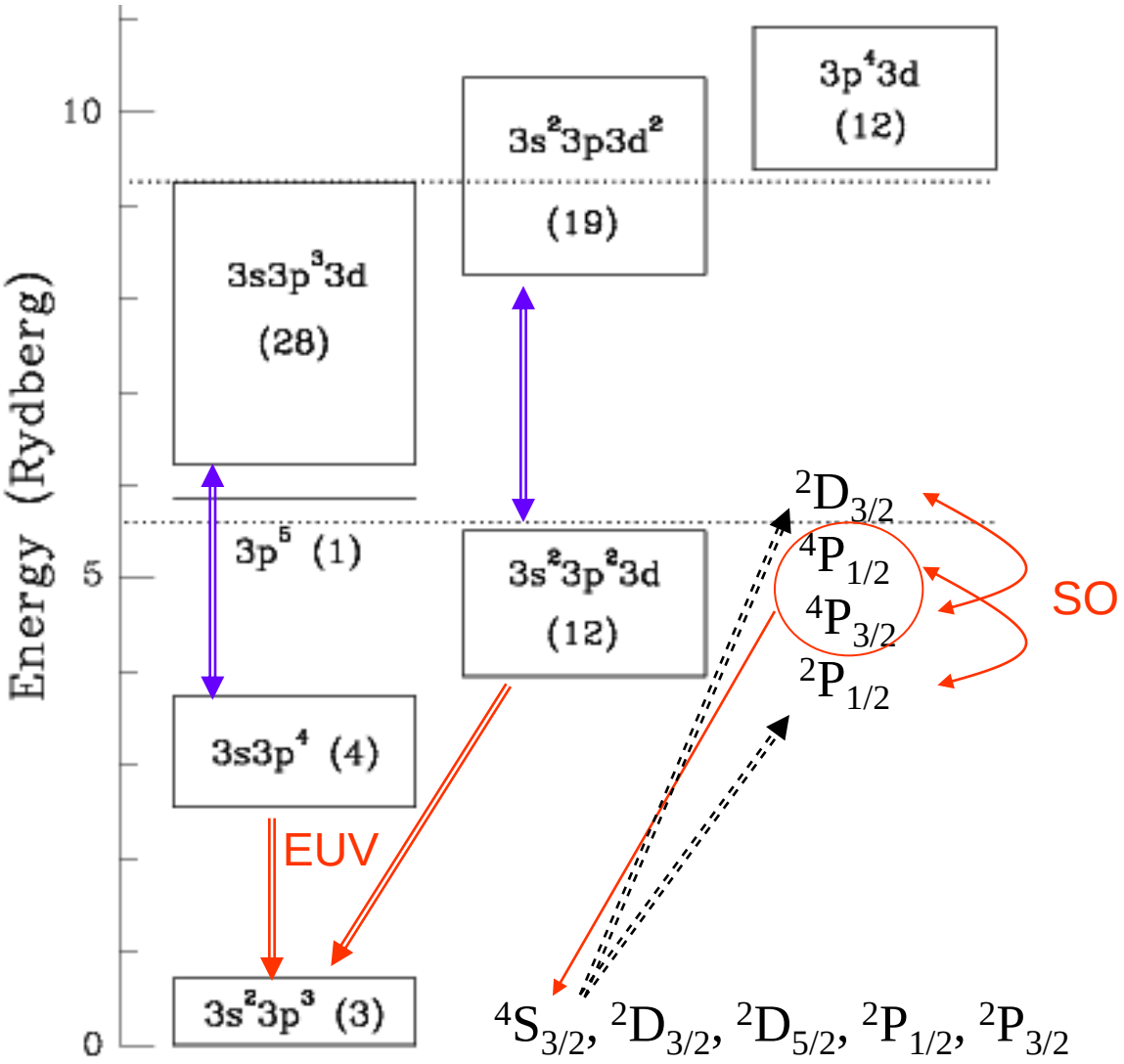
- UK, USA, Italy
- First database to make atomic data freely available for astrophysics
- First released in 1996
- Latest release, 2012, v7
- Complete coverage in X-ray and EUV wavelength range
- Over 1000 citation

CHIANTI - v7.1 (2013)



The top panel shows a section of the *Chandra* spectrum of Procyon, and the bottom panel shows synthetic spectra produced with CHIANTI 6 and CHIANTI 7.1. (Courtesy P.R. Young)

Atomic Data: Scattering calculation for Fe XII



Serious problems with the Fe XII spectrum.

Many calculations:

Flower (1977)

Binello et al (several papers)

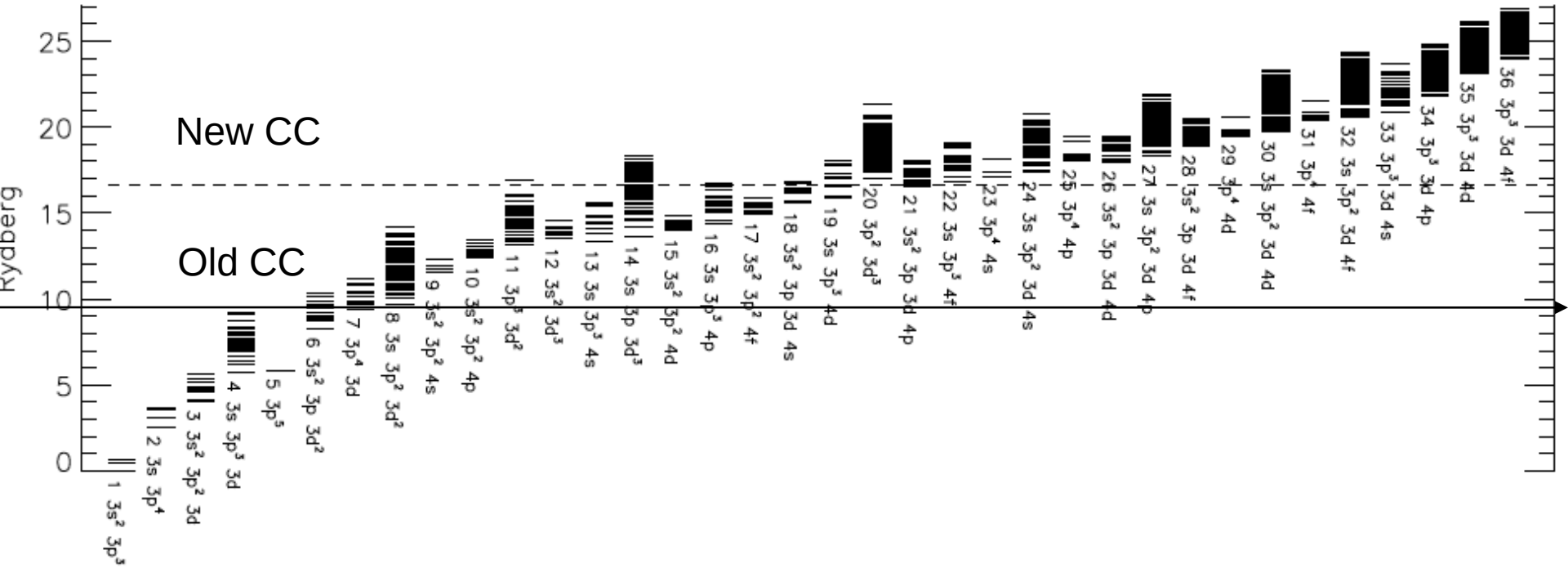
Storey Del Zanna, Mason (2005)

Del Zanna (2012)

UK APAP Team: FeXII

Del Zanna, Storey, Badnell and Mason (2012) - new Fe XII atomic data

The previous R-matrix calculation (Storey et al. 2004) has been extended to include all main n=4 levels (for the soft X-rays)



Solar Flares: X-ray Spectroscopy

Solar Maximum Mission

Gabriel and Mason, 1982

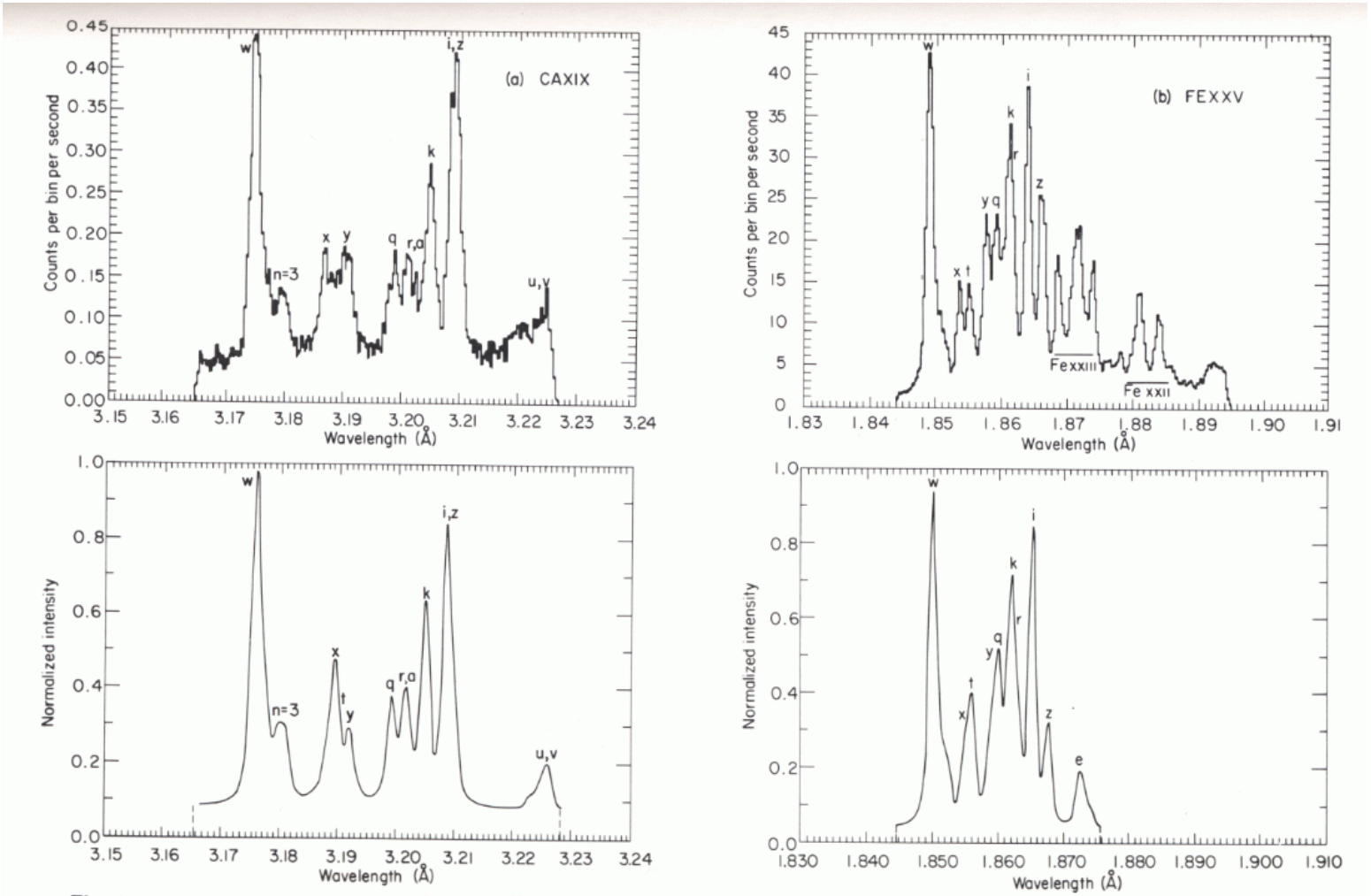


Fig. 8. Solar flare spectra of (a) calcium and (b) iron, observed with the bent crystal spectrometer in the x-ray polychromator experiment (XRP). Shown for comparison are fitted spectra computed using the atomic theory described in the text. The notation for the lines is taken from Gabriel (1972).

Atomic Data for X-ray Spectroscopy

Di-electronic Recombination
Alan Burgess, Nigel Badnell
and Alan Gabriel

Work with French Colleagues,
Non-Thermal and Non-equilibrium effects

- ***Effects in Soft X-ray Flare Spectra***
  Gabriel et al, 1983, Sol. Phys., 86, 59
- ***The OVII Soft X-ray Spectrum and its Application to Hot Plasmas in Astrophysics***
  Gabriel et al, 1991. ApJ, 378, 438.
  Puppis A supernova remnant –
  Non Thermal electrons?

THANK YOU, ALAN

Firenze – 1975
1st European Solar
Physics Conference

Cambridge, 2010

**ps... we may not remember all the details of the atomic structure...
but we can still appreciate a good glass of wine!**