

Benchmarking atomic data for the coronal ions

Giulio Del Zanna
DAMTP, University of Cambridge UK

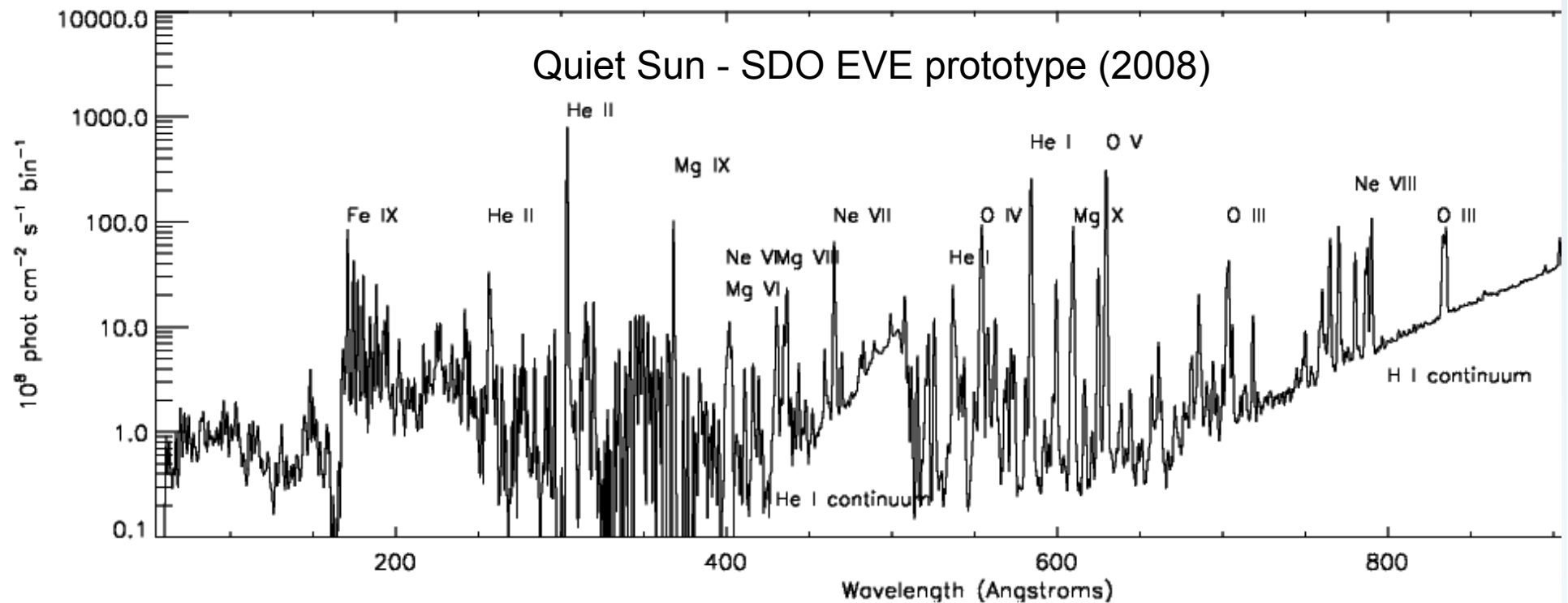


Science & Technology
Facilities Council



UNIVERSITY OF
CAMBRIDGE

The solar EUV



SOHO/CDS/NIS



Hinode/EIS



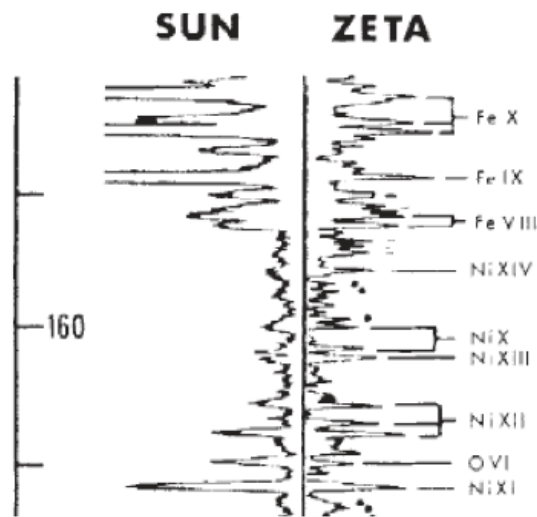
SOHO/SUMER

'You could spend a lifetime to understand this spectrum' (P. Storey)

Solar corona in the EUV

NATURE

May 22, 1965

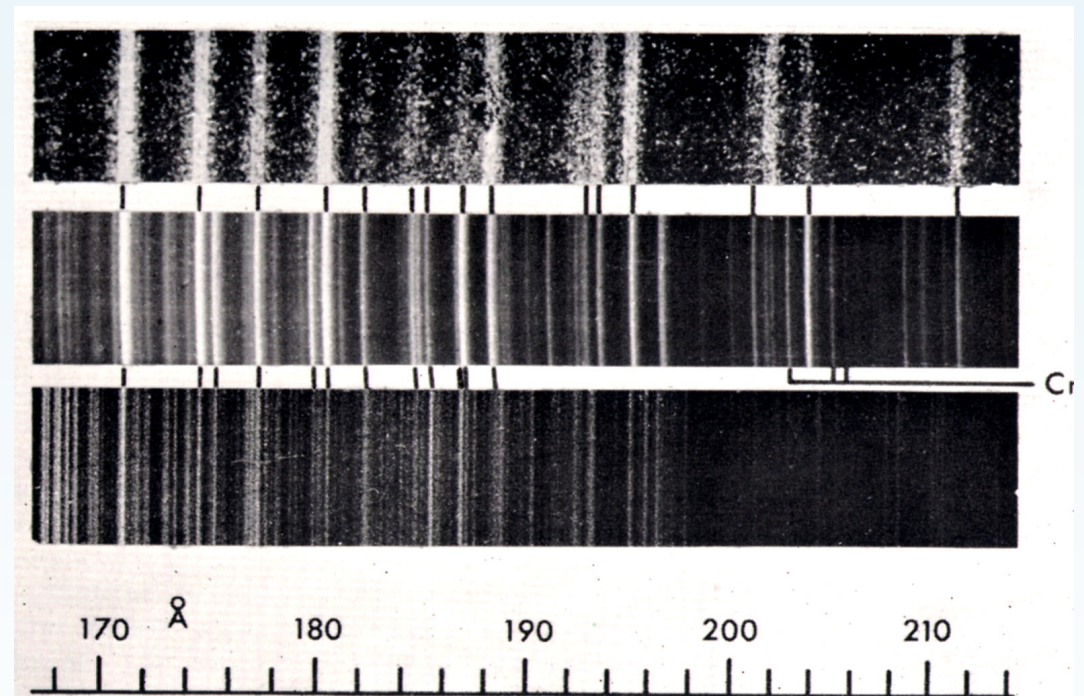


Gabriel & Fawcett (1965)

Sun

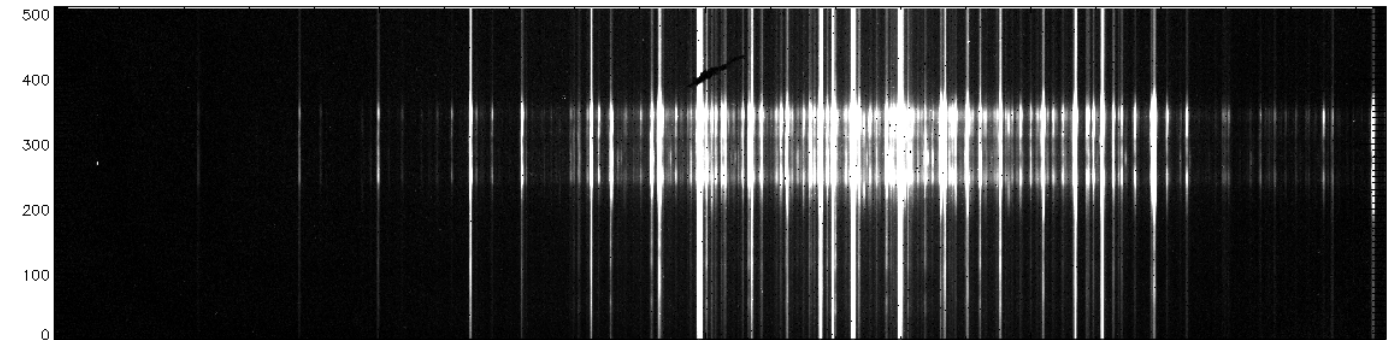
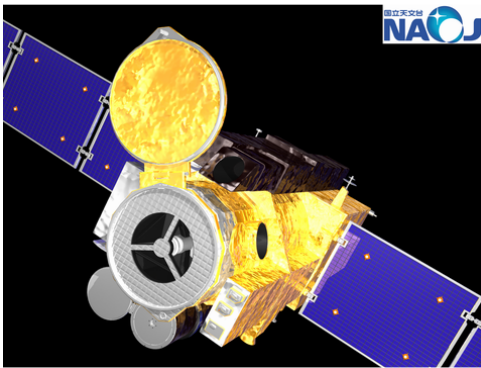
ZETA

iron
spark

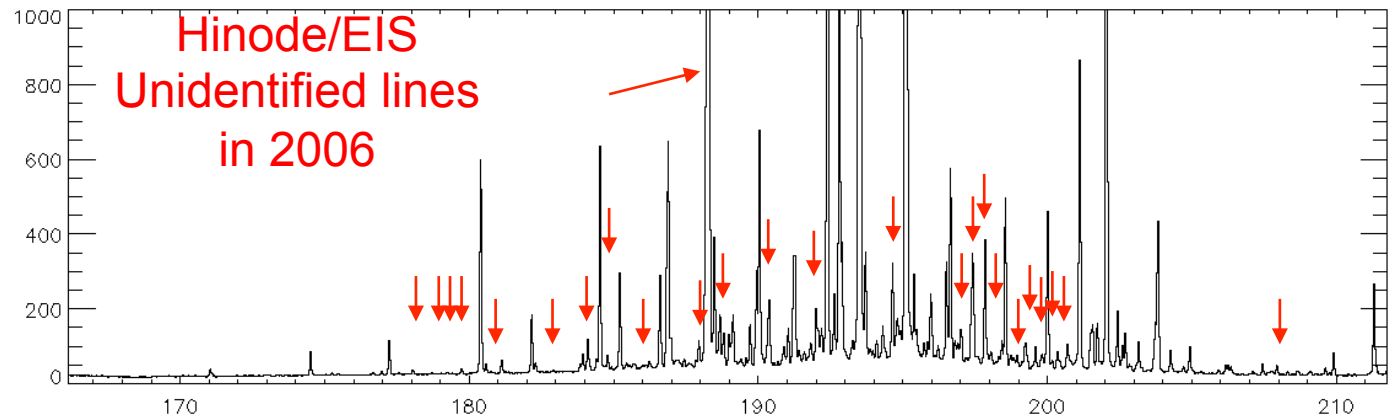


Fawcett, Gabriel & Jordan (1965)
 $3p^n - 3p^{n-1}3d$ transitions in Fe IX to Fe XIV

Hinode EIS and Culham plates



Resolution almost as good as Culham plates which were key for the identifications.



Del Zanna (2011): most brightest coronal lines finally identified after 8 years!



Benchmarking atomic data (Del Zanna 2003-date)

- 1) Find the best atomic structure.
- 2) Calculate e excitation rates (R-matrix) and build ion model to calculate line intensities.
- 3) Compare observed and theoretical wavelengths and intensities for low- and high-density plasmas.

RESULTS: a large number of new identifications and revised wavelengths (with uncertainties). New Ne, Te diagnostic applications

- Fe VII: Del Zanna (2009a) new IDs, new Te diagnostics
- Fe VIII: Del Zanna (2009b) new IDs, new Te diagnostics
- Fe X: Del Zanna+ (2004, 2012) new IDs, new Te diagnostics
- Fe XI: Del Zanna (2010,2012) new IDs, new Te diagnostics
- Fe XII: Del Zanna & Mason (2005); Del Zanna (2012) new IDs
- Fe XIII: Del Zanna (2011a) new IDs
- Fe XIV: Del Zanna (2012) new IDs
- Fe XVII: Del Zanna & Ishikawa (2009) new IDs ; Del Zanna (2011): new Te diagnostics
- Fe XVIII: Del Zanna (2006) new IDs, new Te diagnostics
- Fe XXIII Del Zanna et al. (2005) new Ne,Te diagnostics
- Fe XXIV Del Zanna (2006) new Ne,Te diagnostics

Atomic data calculations and distribution

STFC-funded UK **APAP Network** <http://www.apap-network.org/>
has become the main atomic data provider.

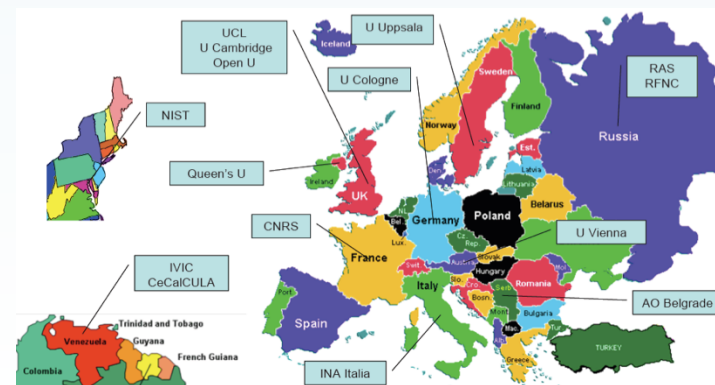
N. Badnell, L Fernandez-Menchero (Strathclyde),
P. Storey (UCL), H. Mason and G. Del Zanna (Cambridge)

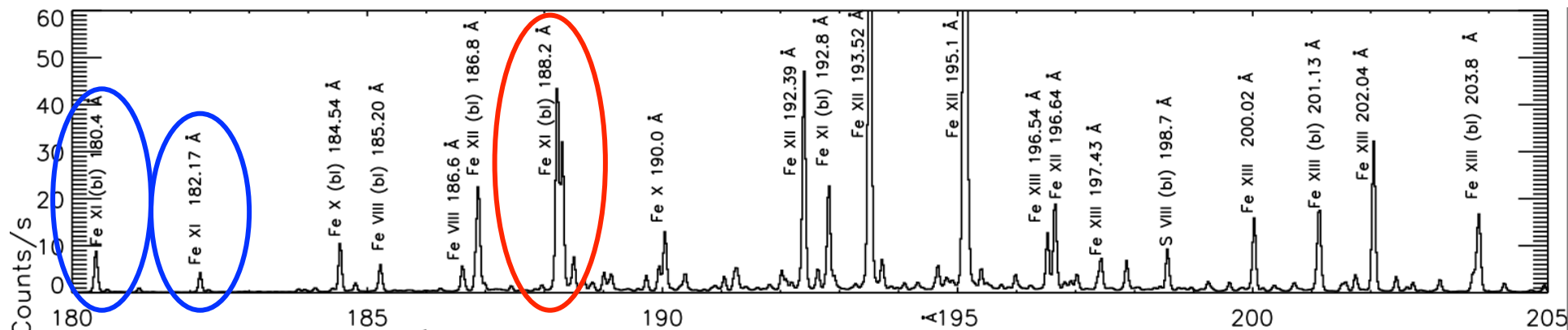
Electron impact excitation data have been produced with large-scale R-matrix calculations for all ions of astrophysical importance of **the H-, He-, F-, Na-, Ne-, Li-, and B-like isoelectronic sequences**, as well as for a large number of individual ions, in particular **Fe VII, Fe VIII, Fe IX, Fe X, Fe XI, Fe XII Fe XIII, Fe XIV, Fe XVII, Fe XVIII, Fe XX, Fe XXIII**

DISTRIBUTION:

-CHIANTI (www.chiantidatabase.org) has now become the reference atomic database for ions, world-wide, with hundreds of citations per year.

-**VAMDC** (Virtual Atomic and Molecular Data Center)
<http://portal.vamdc.eu>





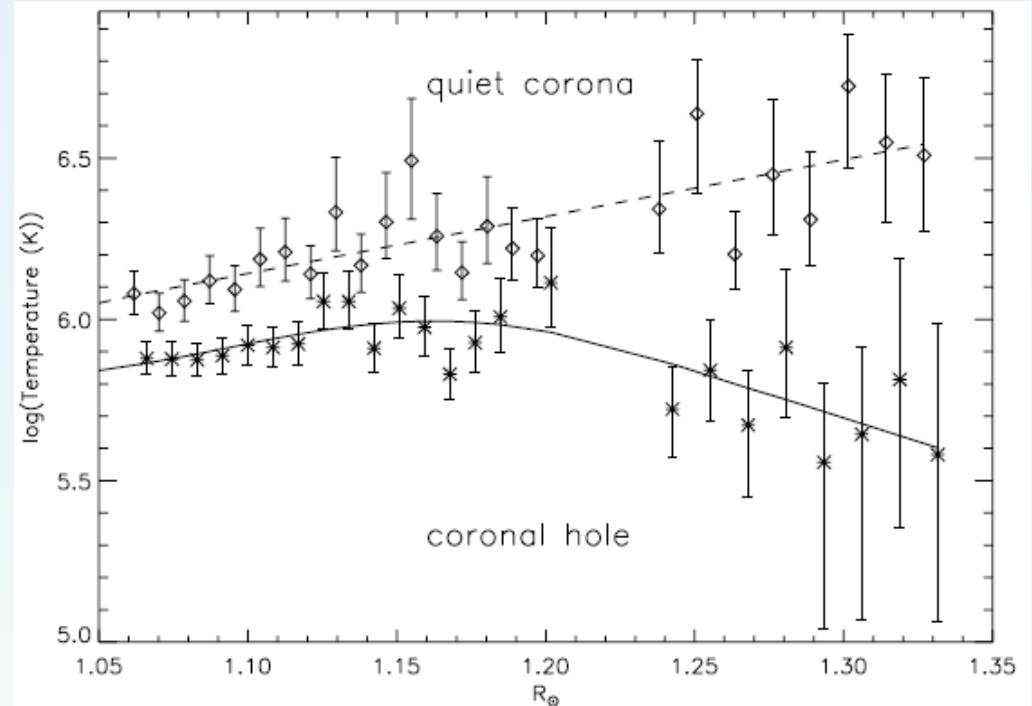
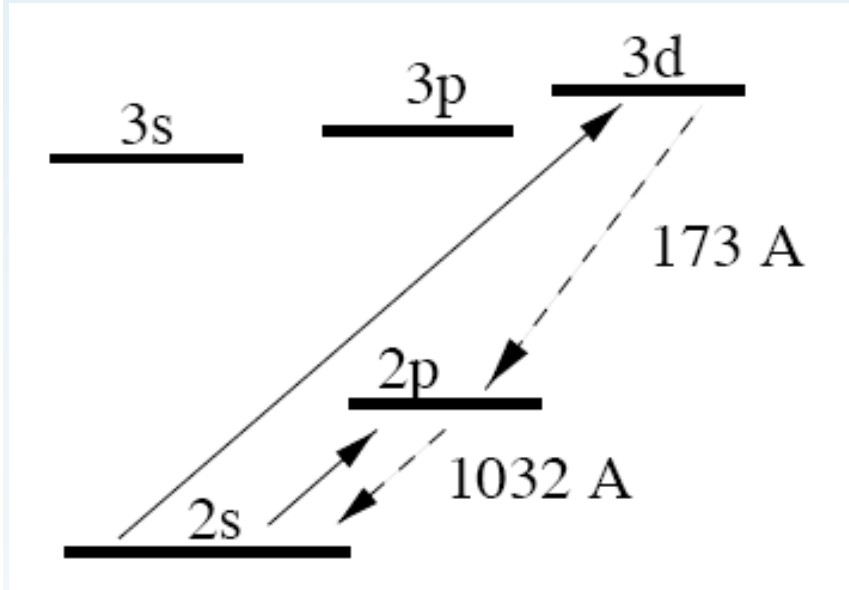
Hinode EIS spectrum

<i>i-j</i>	λ_{exp} (Å)	λ_{obs} (Å)	ID	Diff. ID
6-103	168.929	? 168.929(10) Be76	N	
1-43	178.058	178.056(4) Be76	G66	
4-46	179.758	179.758(10) Be76	G66	
1-42	180.401	180.401(2) Be76 (bl)	G66	
2-44	180.594	180.595(4) Be76	F71	
3-44	181.130	181.131(10) Be76	G66	
2-43	182.167	182.167(2) Be76	G66	
4-45	184.793	184.793(10) Be76 (bl u)	G66	
1-38	188.216	188.216(2) Be76	B77	F71 (188.299)
1-37	188.299	188.299(2) Be76	J93	B77(189.94)
2-41	189.123	189.123(4) Be76 (bl u)	B77	J93 (192.619)
3-41	189.711	189.723(5) N (bl)	B77	
1-36	190.382	190.382(5) N (bl u)	N	Be76 (S xi)
2-39	192.021	192.021(5) N (bl)	B77	
3-39	192.627	192.624(5) N (bl u)	B77	
2-38	192.813	192.811(5) N (bl O v, u)	F71	
3-37	193.512	- (bl Fe xii 193.509(2))		
4-41	198.538	198.555(10) Be76 (bl S viii)	B77	Be76, J93
1-35	201.112	201.112(5) N (bl Fe xiii)	N	
4-39	201.734	201.734(10) Be76 (bl Fe xii)	B77	
1-34	202.424	202.424(10) Be76 (bl u)	N	B77 (201.575)
4-38	202.609	- (bl S viii 202.608(10))		
4-37	202.705	202.710(10) Be76 (bl)		
1-30	206.169	206.169(10) Be76 (bl u)	N	
1-29	206.258	206.258(5) N	N	
2-34	207.751	207.749(5) N (bl u)	N	
2-33	209.771	209.771(5) N (bl u)	N	
1-20	234.730	234.73(2) D78	N	D78 (Fe xv)
1-18	236.494	236.494(10) Be76	N	
1-17	239.780	? 239.78(2) D78	N	
1-16	240.717	240.713(4) Be76 (bl Fe xiii)	N	
1-15	242.215	242.215(10) (bl) Be76	N	

Gabriel et al.(1966)

Fe XI benchmark: Del Zanna (2010)
31 (out of 60) new line identifications

'Direct' temperature diagnostics



Ratios of lines with very different excitation energies.

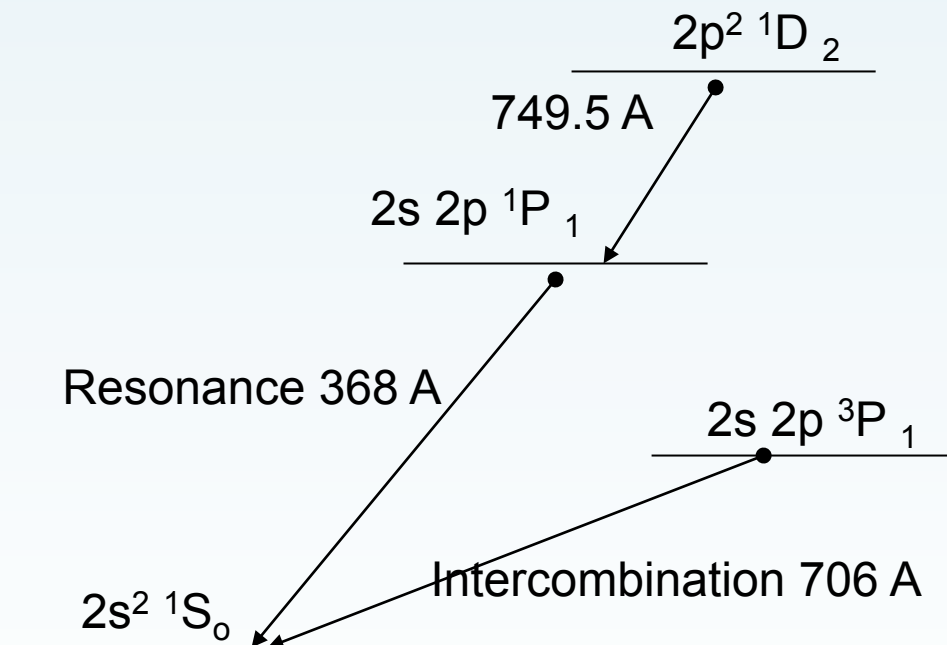
O VI SOHO CDS GIS and SUMER

David, **Gabriel**, Bely-Dubau, Fludra, Lemaire, Wilhelm (1998)

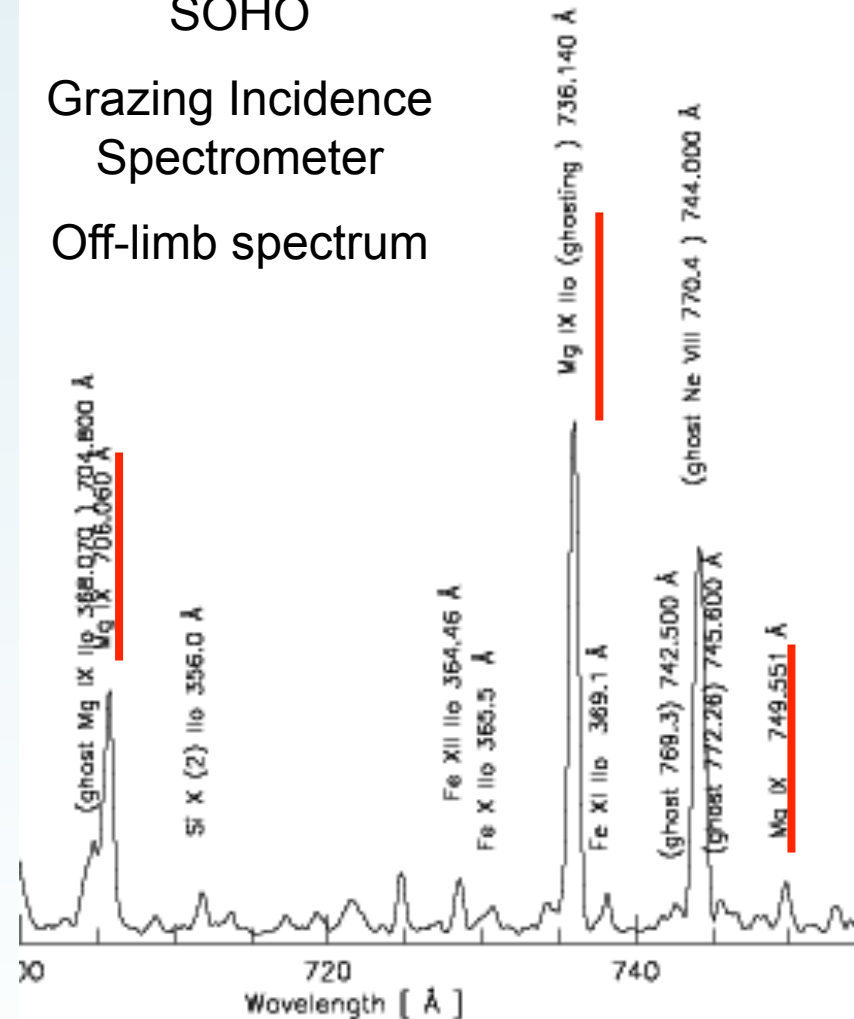
Te from Mg IX

First atomic calculation for Mg IX
(Del Zanna+2008) resolved significant
discrepancies

Best(?) Te diagnostic for the 1 MK corona
(Solar Orbiter SPICE)

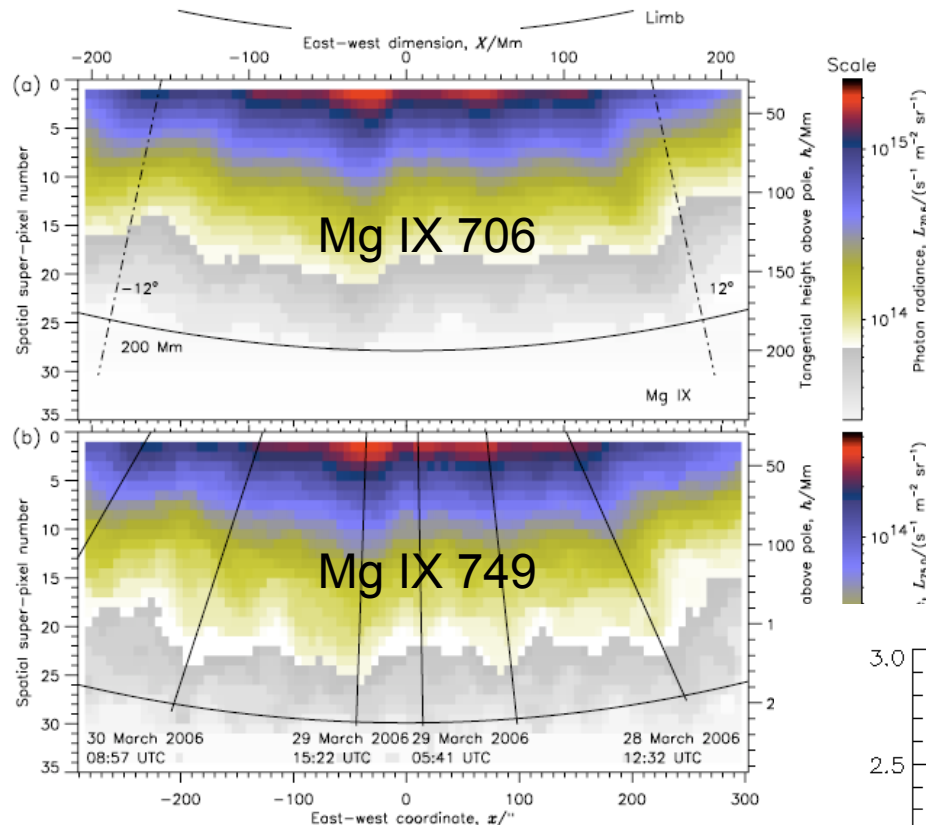


SOHO
Grazing Incidence
Spectrometer
Off-limb spectrum



Del Zanna (1999 - PhD thesis)

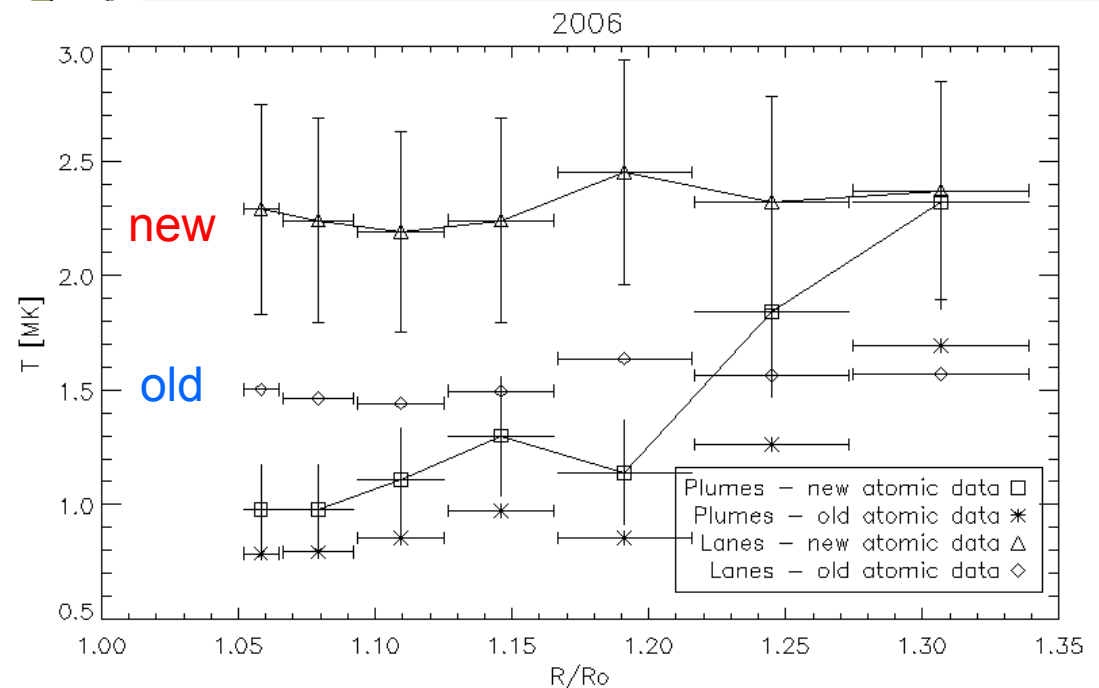
Te in coronal holes



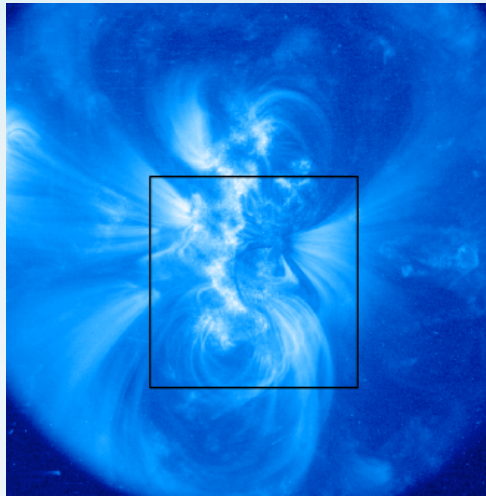
SUMER (2006)
‘New’ Te obtained including
photoexcitation and (small)
density effects.
(Del Zanna, Teriaca, Wilhelm)

Temperatures with the new
atomic model are higher.

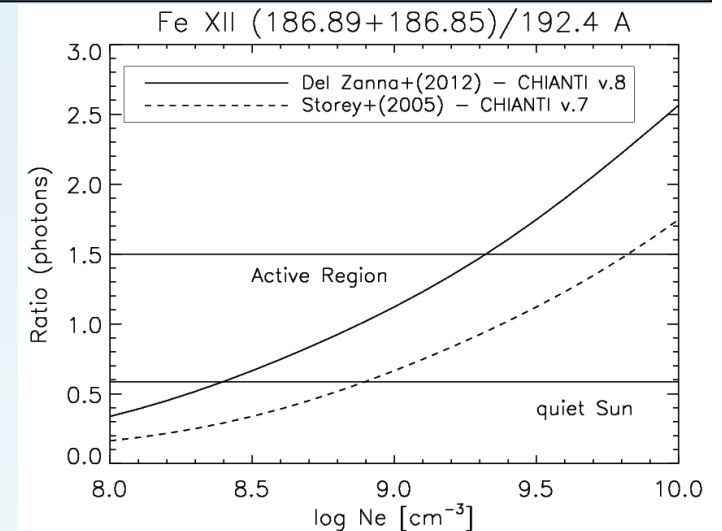
E.g. an inter-plume
Te=850 000 at 1.3R revised to
1 160 000 K (Del Zanna+2008)



Measuring Ne in a solar active region



Hinode/EIS Fe XII line ratios provide accurate density maps but we sorted the atomic data only in 2012!



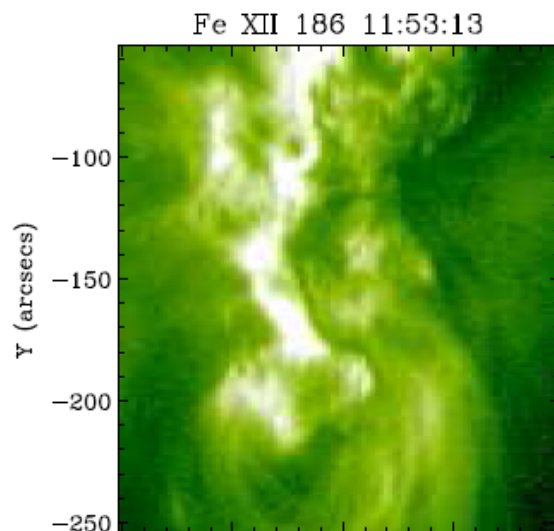
Self-blend decay
to excited state

(Del Zanna & Mason 2005)

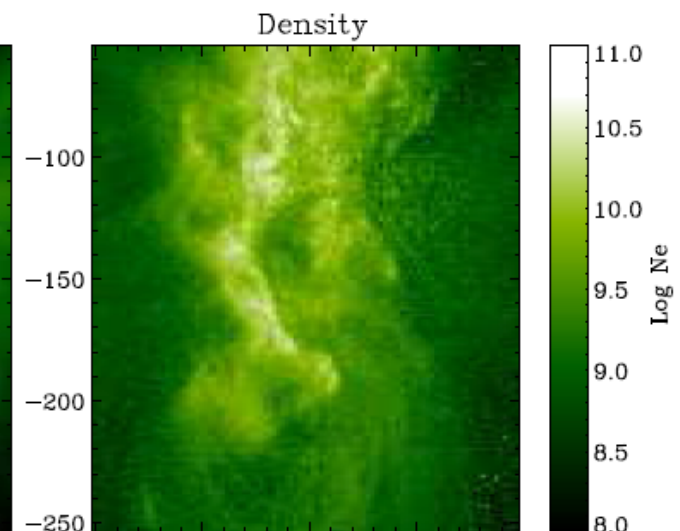
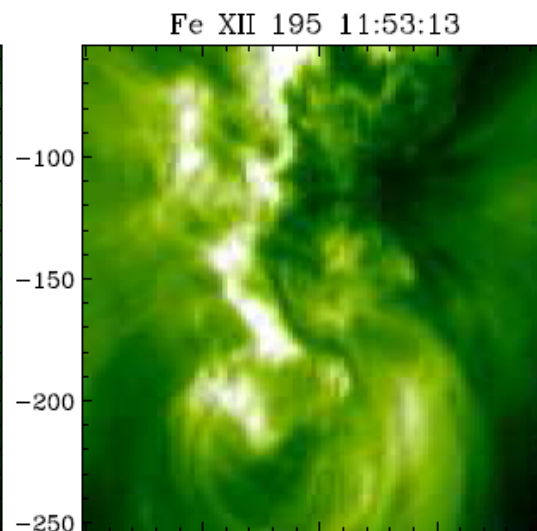
Self-blend decay
to ground state

(Del Zanna & Mason 2005)

Density



G. Del Zanna - IAS 2013



Tripathi et al. (2009)

Long life to Alan and all spectroscopists !

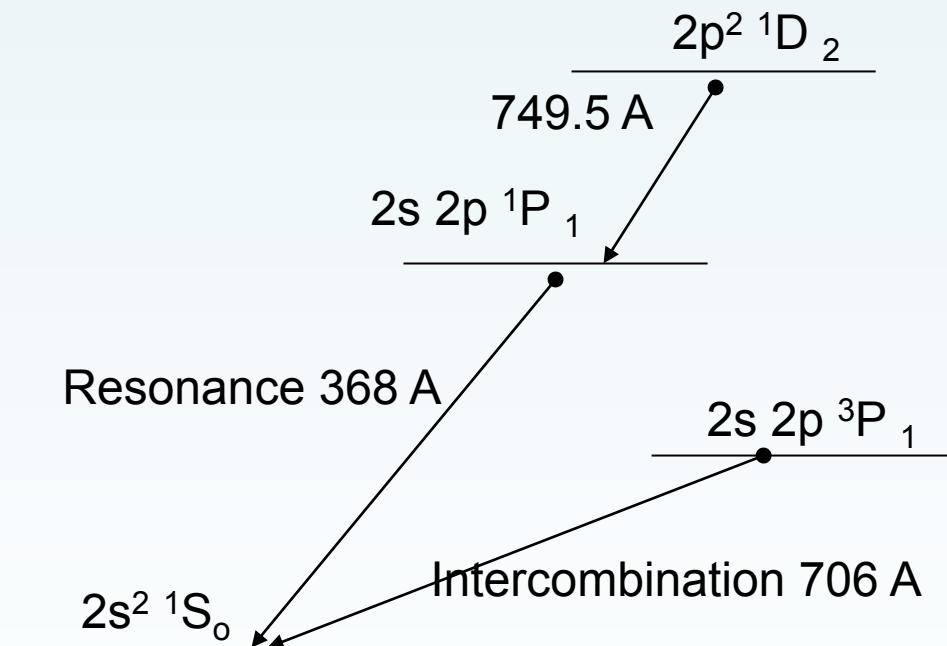


Alan always has his priorities right !

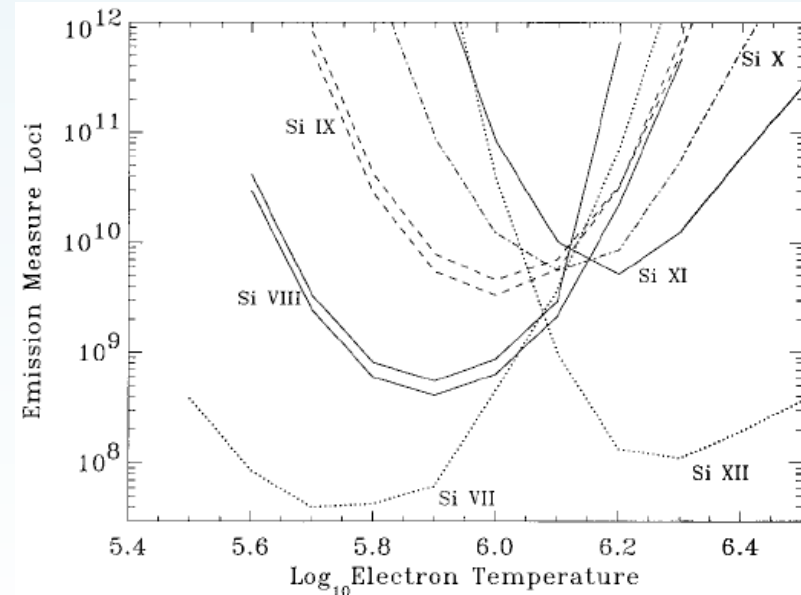
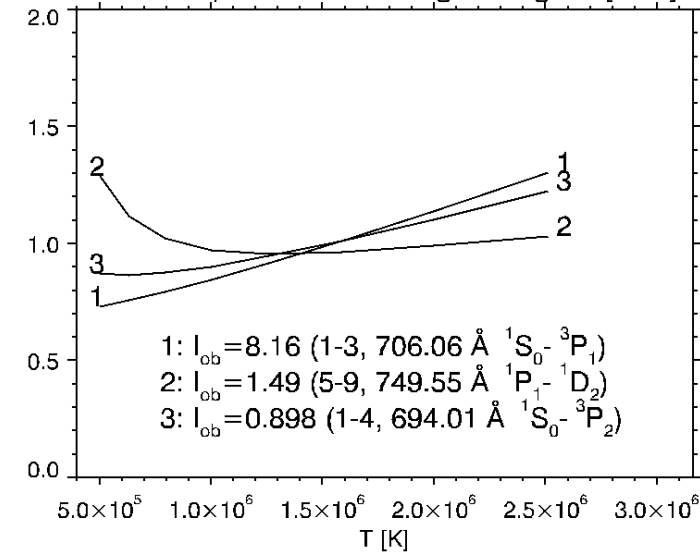
EXTRA SLIDES

Te from Be-like Mg IX

Best Te diagnostic for the 1 MK corona.
First R-matrix calculation for Be-like Mg
(Del Zanna Rozum Badnell 2008) resolved
significant problems: **Te in CH underestimated
by a factor of 2**

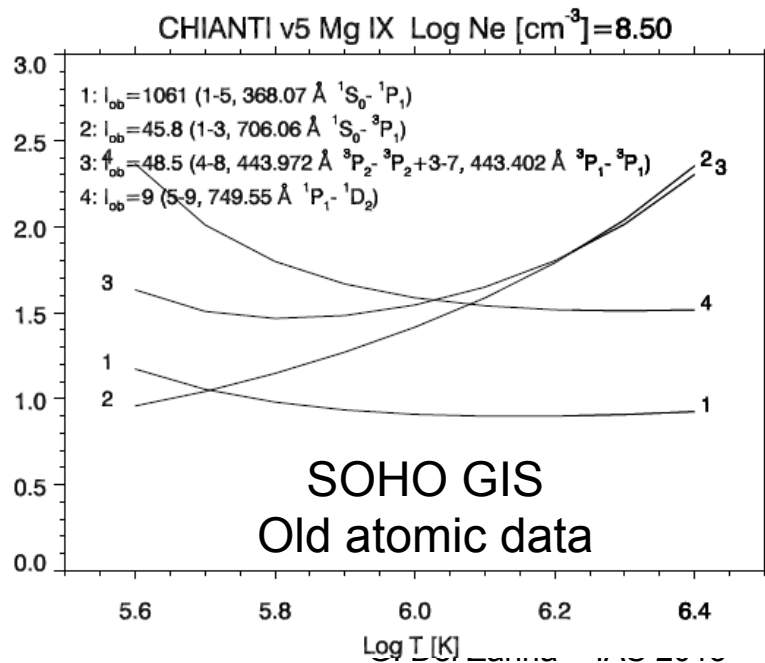
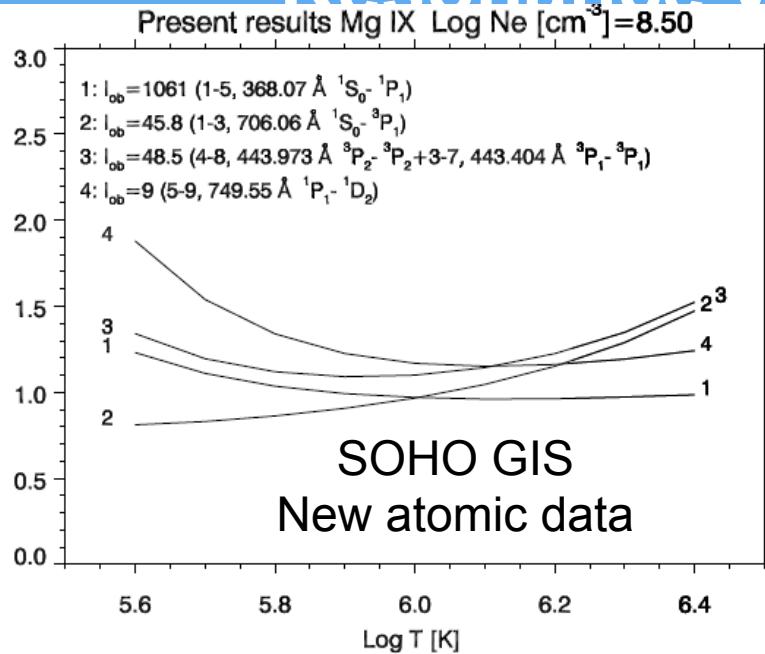


SOHO SUMER present results Mg IX $\text{Log Ne [cm}^{-3}] = 8.2$

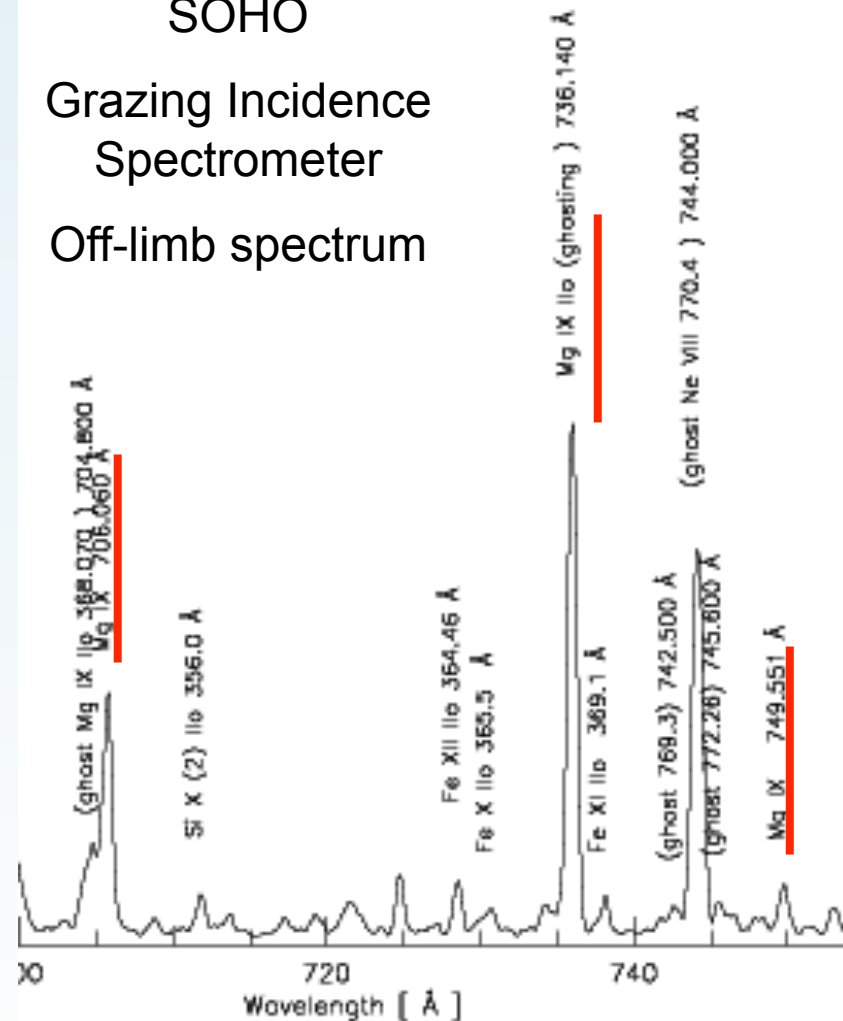


Te=1.35 MK (Feldman et al. 1999)

Resonance vs. intercombination



SOHO
Grazing Incidence
Spectrometer
Off-limb spectrum



Del Zanna (1999 - PhD thesis)

Fe XII

Del Zanna (2012): the population of the $3s^2 3p^3 \ ^2D_{5/2}$ is 50 % higher than previous models (Storey et al. 2005; Del Zanna & Mason 2005)

