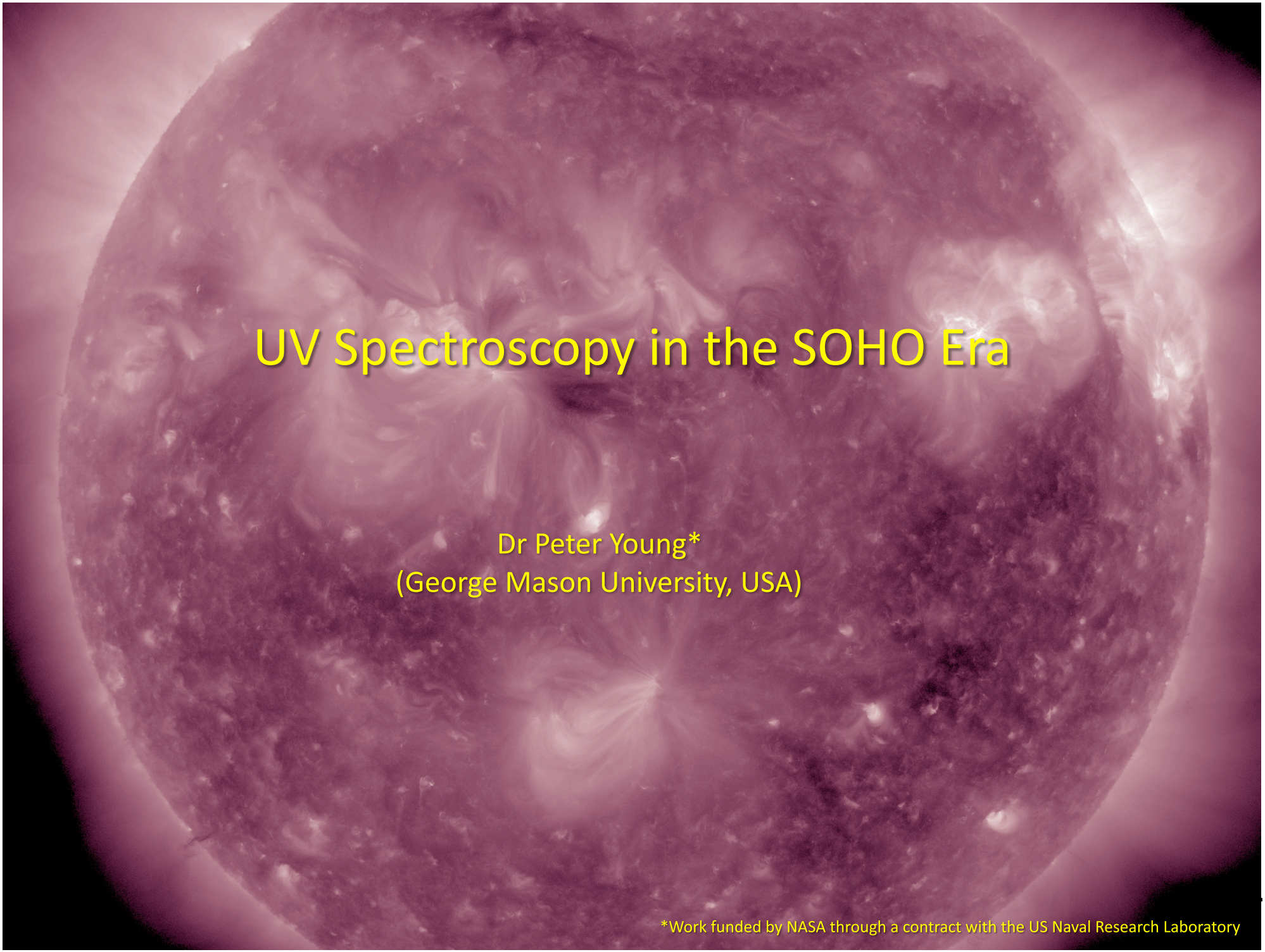


UV Spectroscopy in the SOHO Era

Dr Peter Young*
(George Mason University, USA)

*Work funded by NASA through a contract with the US Naval Research Laboratory

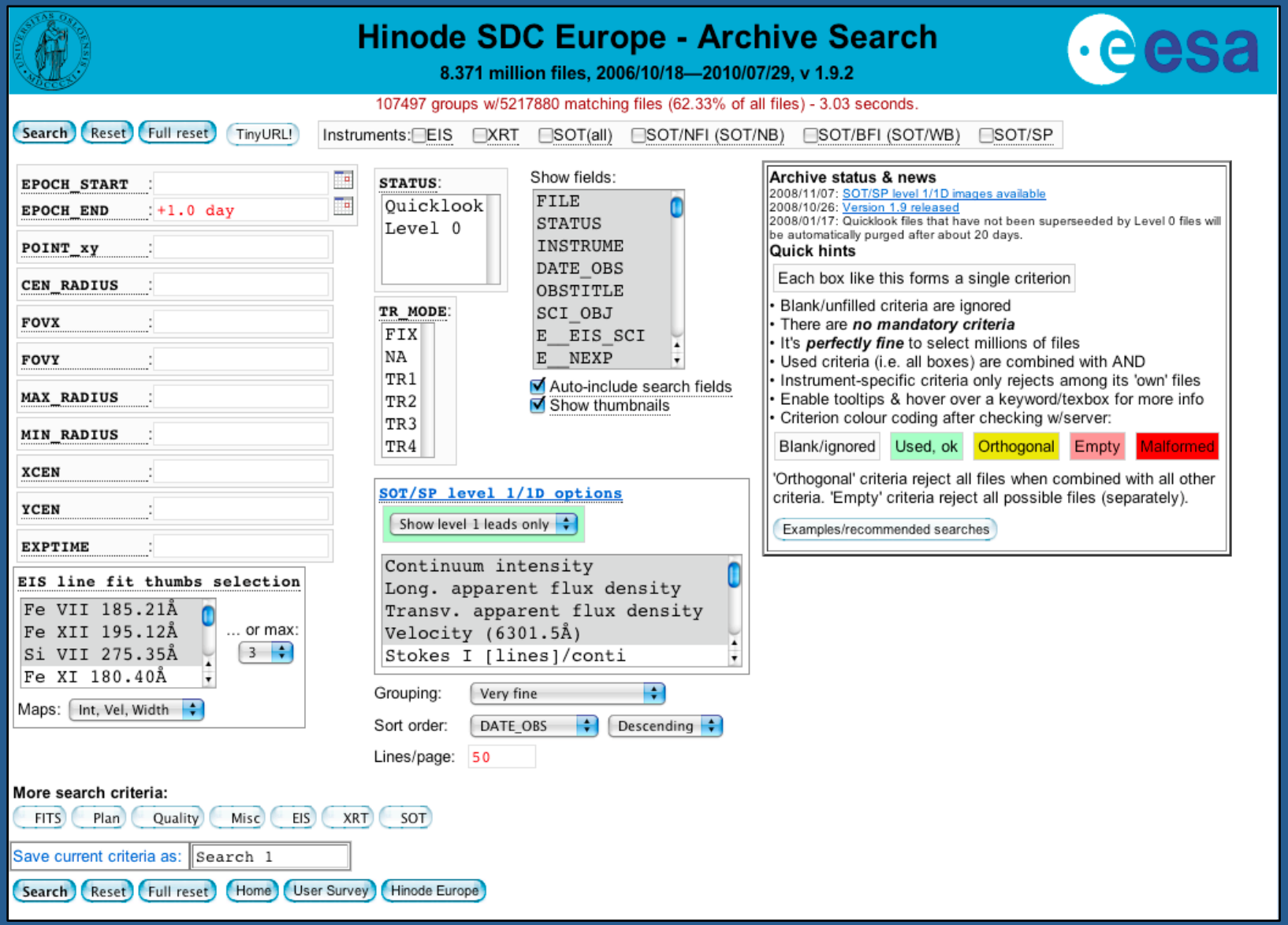
Timeline

1993	I started my PhD with Helen ☺
1993	First Iron Project paper
1994	First web browser available (Mosaic)
1995	SOHO launched
1996	CHIANTI released
2006	Hinode launched

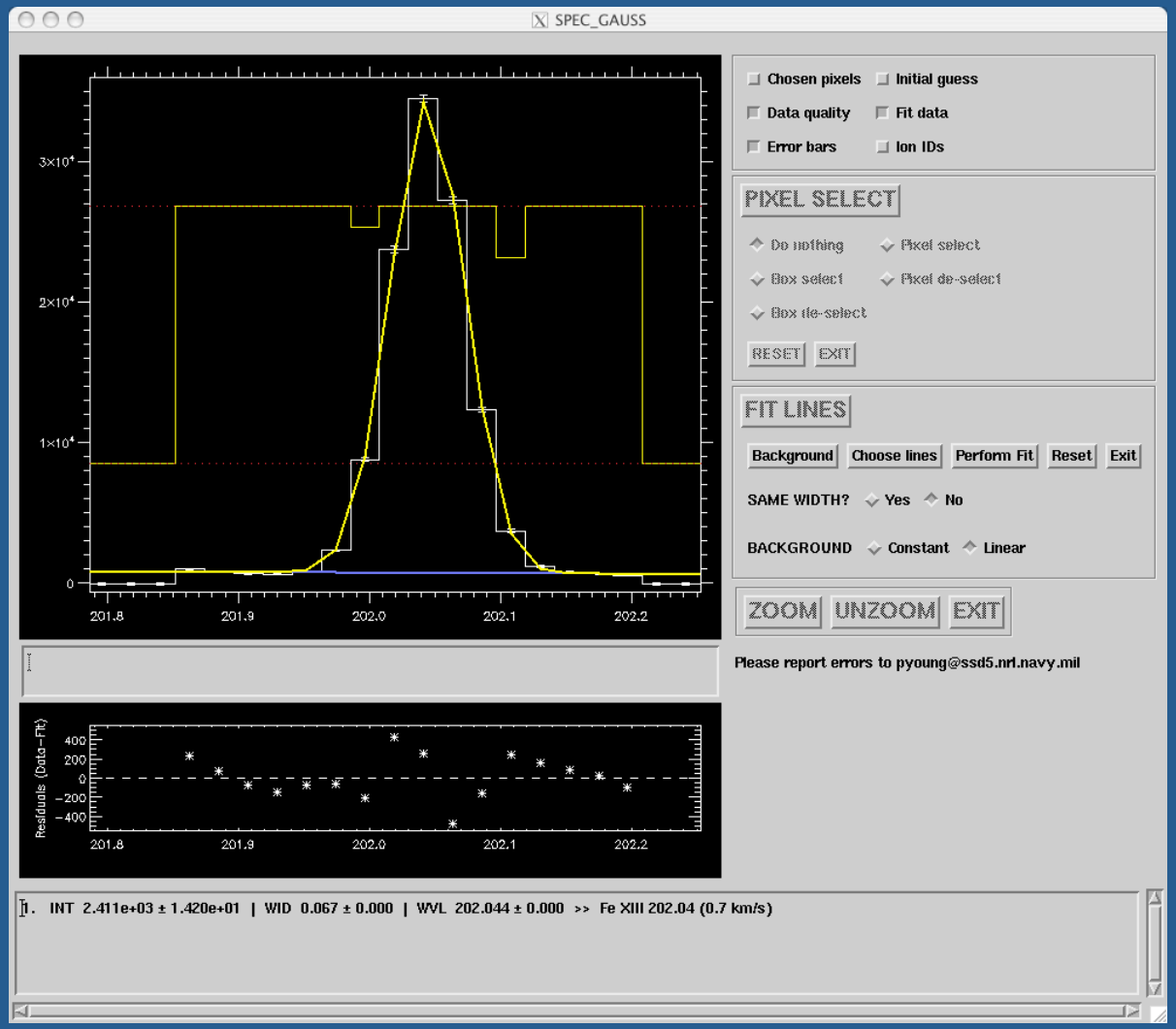
The combination of
1. free access to large volumes of UV spectral data;
2. high quality atomic data;
3. the CHIANTI database; and
4. free analysis software and web documentation.

have been the main changes to UV spectroscopy over the SOHO era.

Web search tools



Free software for line fitting



CHIANTI

CHIANTI

An Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas.

Home	Download	Help	User Guides	Direct Access	News-History	CHIANTI and Other Codes
Team	Line Lists	Links	ADS Citations	Acknowledging CHIANTI	CHIANTI Papers	CHIANTI Family

Naval Research Laboratory (USA) - George Mason University (USA) - University of Cambridge (UK) - Universita' degli Studi di Firenze (Italy)

CHIANTI consists of a critically evaluated set of up-to-date atomic data, together with user-friendly programs written in Interactive Data Language (IDL) to calculate the spectra from astrophysical plasmas.

The CHIANTI package is freely available to all researchers.
If you use the package, we only ask you to appropriately acknowledge CHIANTI .

CHIANTI team receives award from the Royal Astronomical Society!

- The Chianti wine-producing area of Tuscany, Italy -

On January 8 2010 the CHIANTI team were awarded the Group Achievement Award for Geophysics by the Royal Astronomical Society (UK). The citation was:

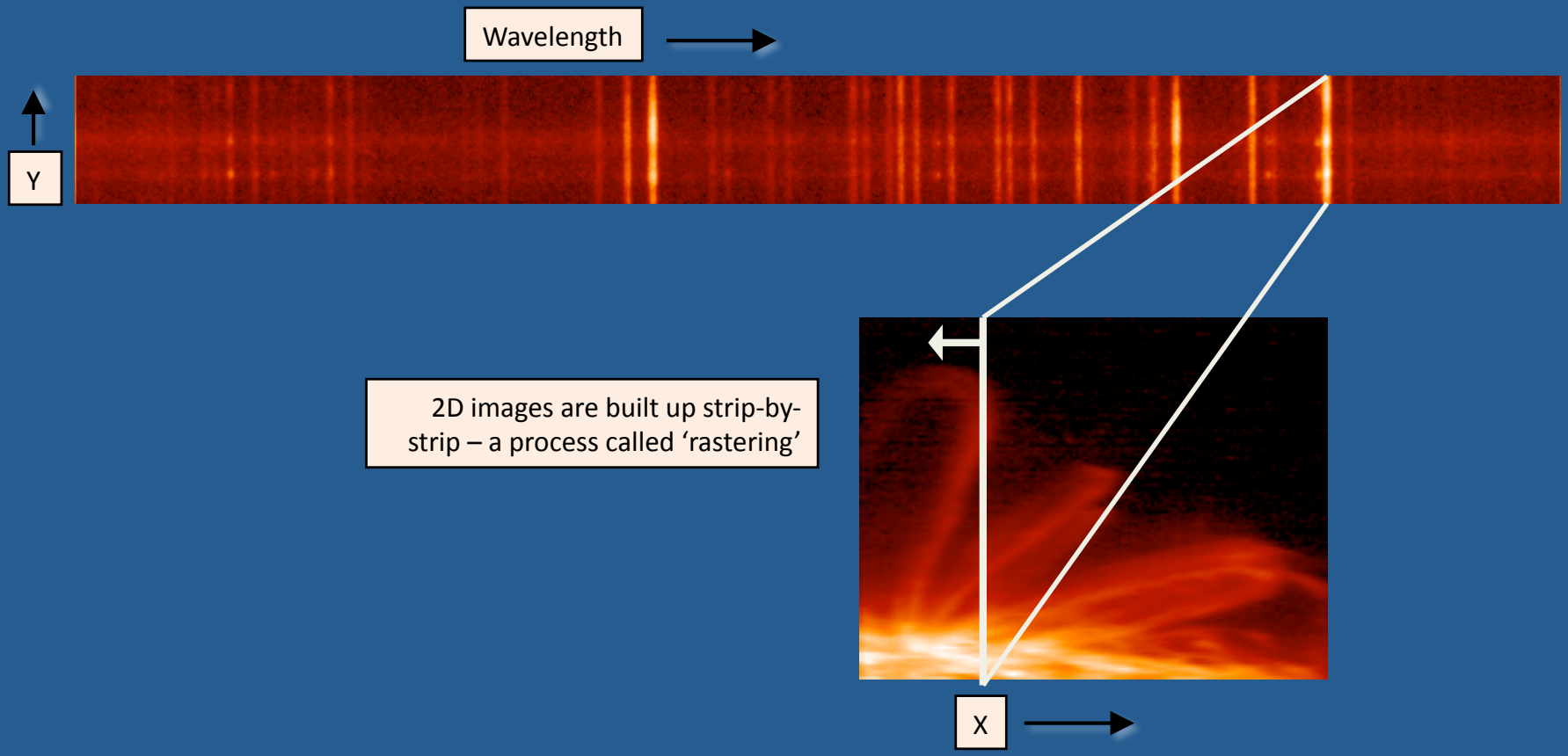
"The Group Achievement Award for Geophysics is given to the CHIANTI consortium, the team of scientists who have developed the 'Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas.' This is a powerful tool for scientists who use the dispersion of light by wavelength (spectroscopy) to measure the properties of astronomical objects, including their composition, temperature, density and magnetic field strength. The analysis requires detailed knowledge of a large range of atomic elements. The CHIANTI consortium's achievement is the establishment of a systematic, easy-to-use and publically available database to assist this process, with a huge impact on solar and stellar physics."

A full press release is available from the RAS website.

We are grateful to individual scientists and funding agencies for their support.

UV spectroscopic instruments

- SUMER & CDS on board SOHO; EIS on board *Hinode*
- Stigmatic instruments: imaging and spectroscopy simultaneously



UV spectroscopy techniques

Old techniques

- Doppler shifts
- Line broadening
- Line ratios (density, temperature)
- Emission measure/differential emission measure
- Element abundances

New techniques

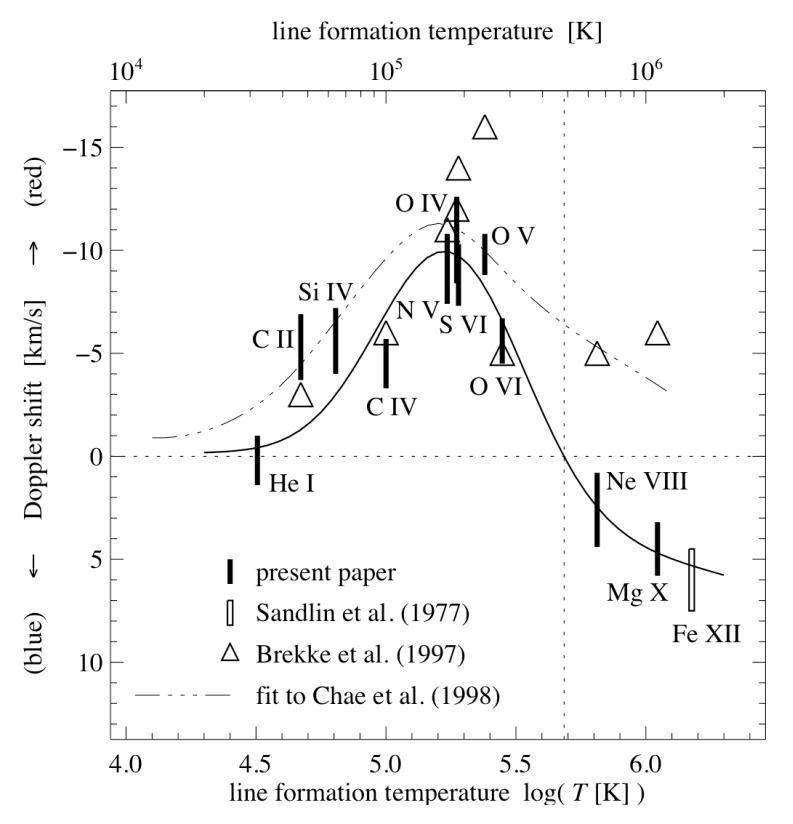
- Coronal seismology
- Forward modelling
- EUV imaging

Pitfalls

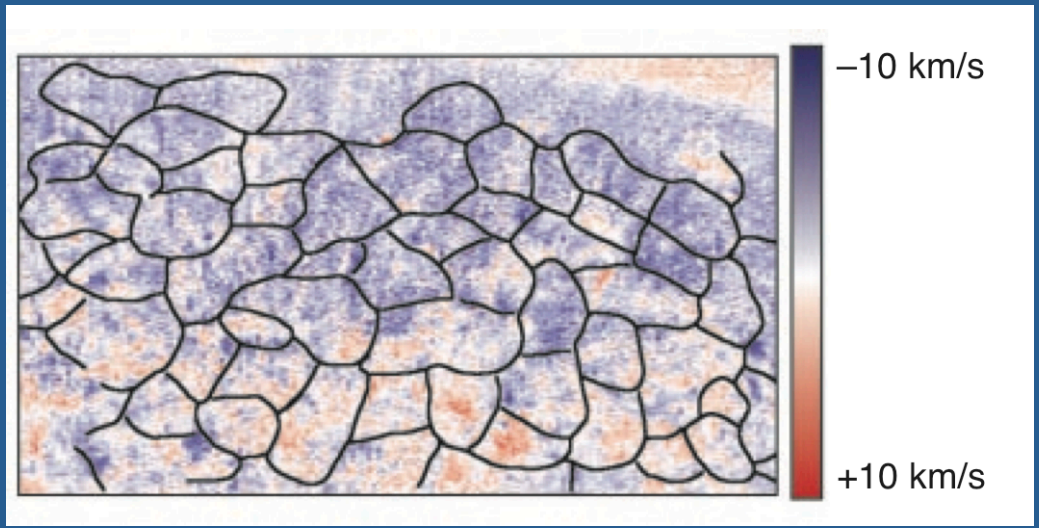
- Time resolution
- Line blending
- Atomic data uncertainties

Doppler shifts

- SOHO/SUMER has yielded high accuracy velocities in the transition region
- Measured average quiet Sun velocity through the transition region
- Detected outflows in coronal holes



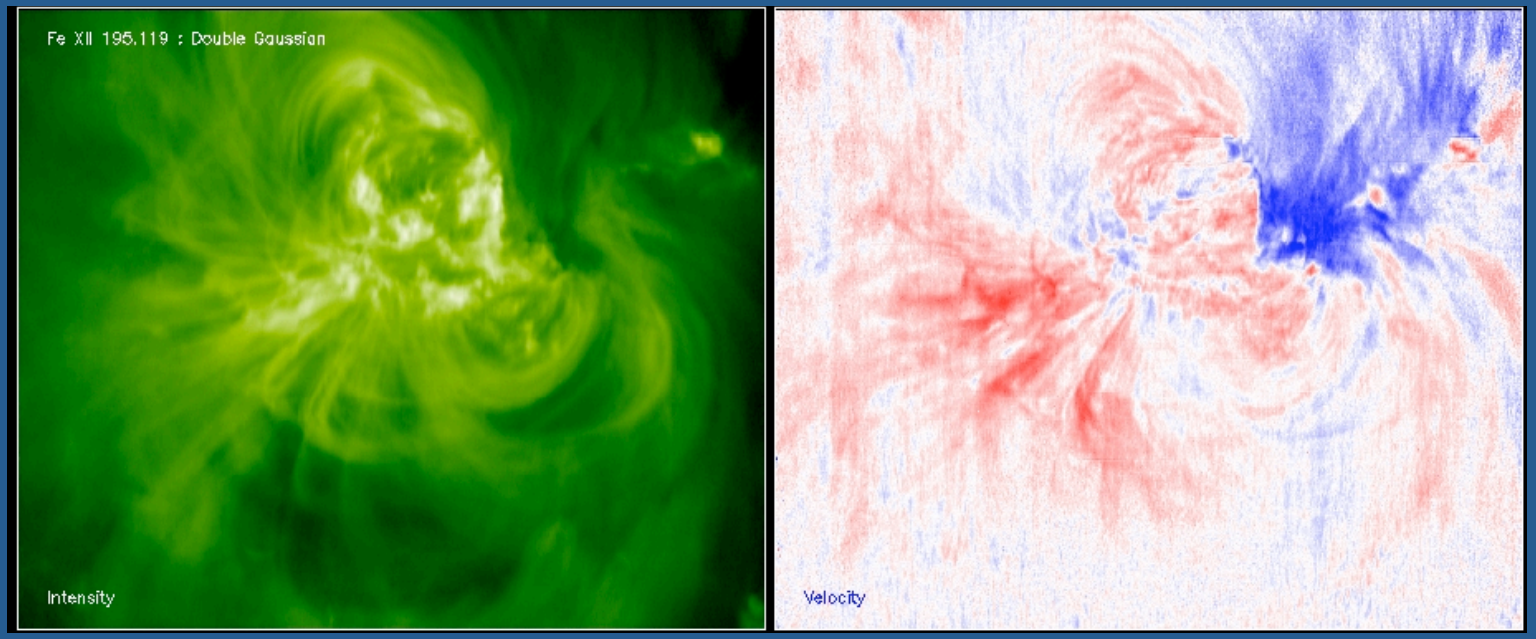
Peter & Judge (ApJ, 1999) [SUMER]



Hassler et al. (1999, Science) [SUMER]

Doppler shifts

- Hinode/EIS now yields high precision coronal velocity maps on a routine basis



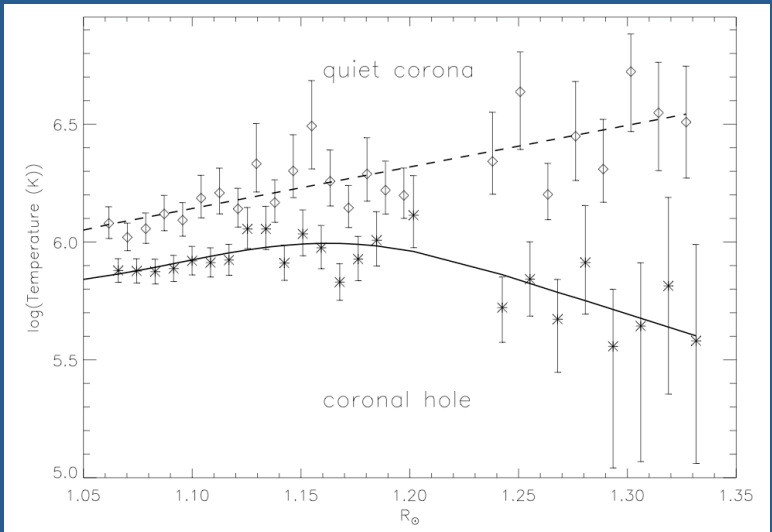
Fe XII λ195.12 intensity and velocity maps for an active region observed on 2007 December 12 (courtesy of H.P. Warren, NRL)

Most active regions show a blueshifted, low intensity region – solar wind source?

Line ratio diagnostics

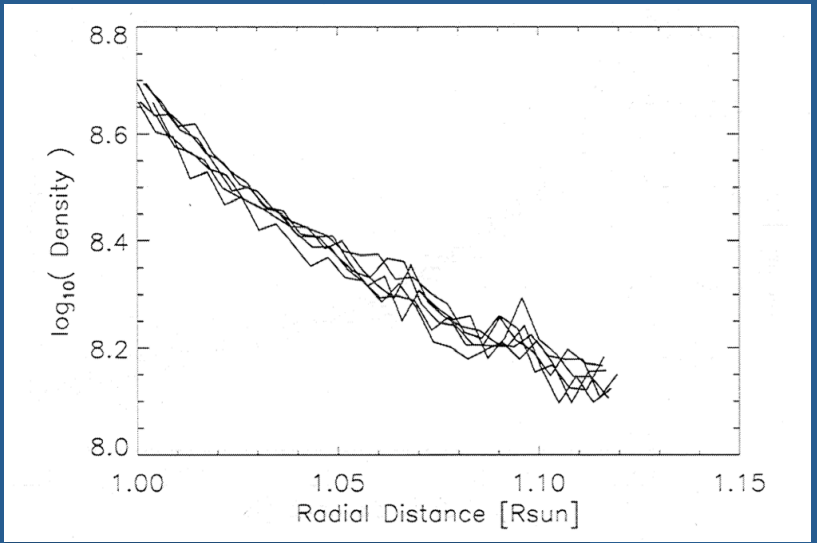
- Line ratios sensitive to temperature and density are commonly applied to solar data

Temperature sensitive O VI λ173/λ1032 ratio



David et al. (A&A, 1998) [CDS,SUMER]

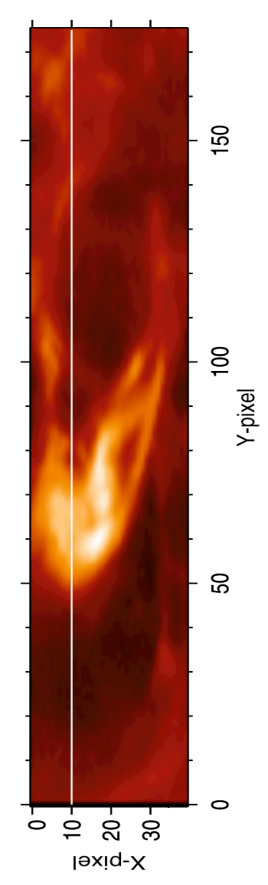
Density sensitive Si IX λ342/λ350 ratio



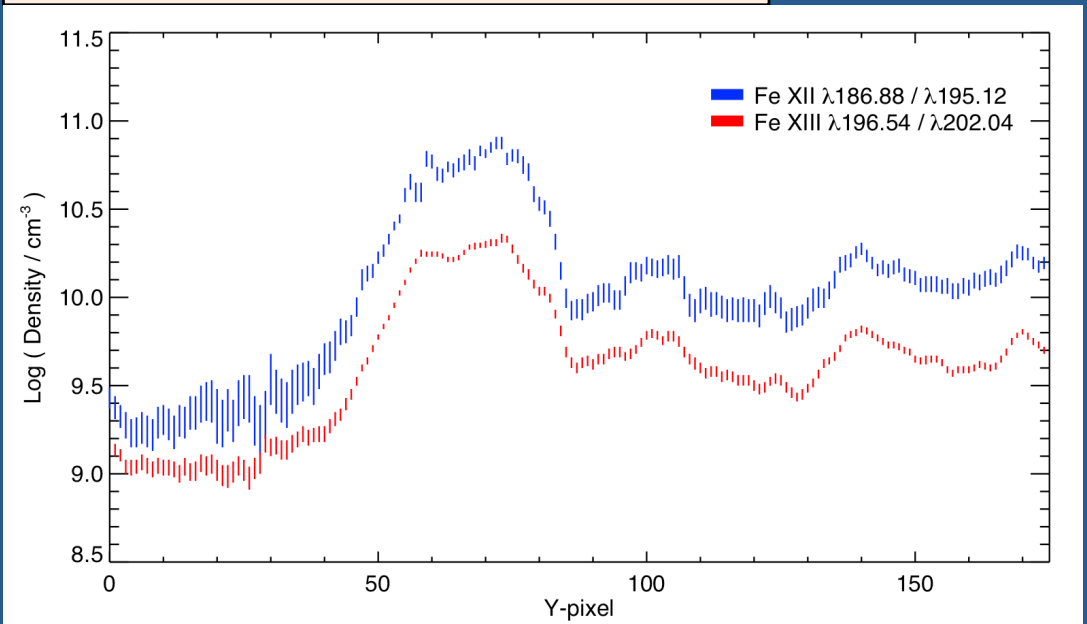
Fludra et al. (JGR, 1999) [CDS]

EIS density diagnostics

- EIS observes the best coronal density diagnostics (Fe XII, Fe XIII)
- Precision of density measurements can be better than 5%...
- …but seems to be problem with atomic data



Density slice through a flaring active region

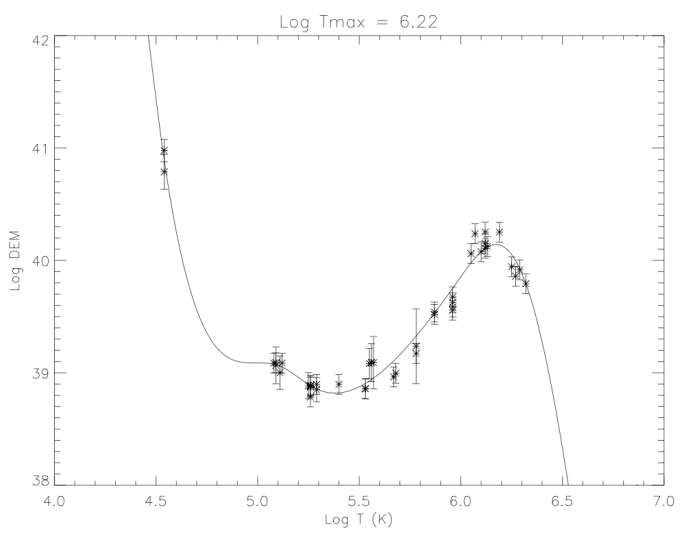


Young et al. (A&A, 2009) [EIS]

(Differential) emission measure

- The DEM describes the distribution of plasma with temperature in the corona

Set of emission line intensities → Inversion/minimization code → DEM(*T*)

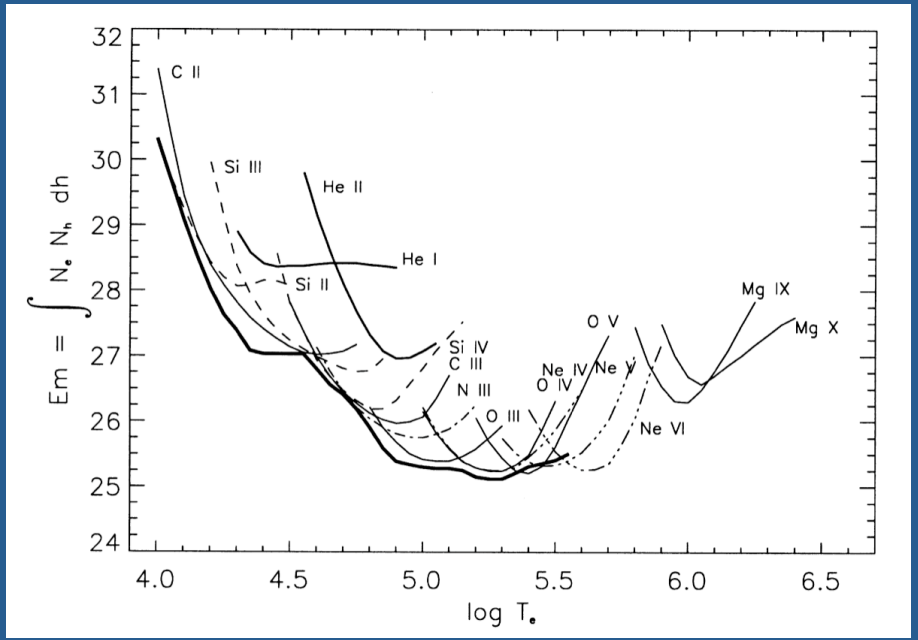


Active region DEM curve
Landi & Landini (1998, A&A) [CDS]

- DEM codes are freely available (e.g., CHIANTI, PINTofALE)

EM loci method

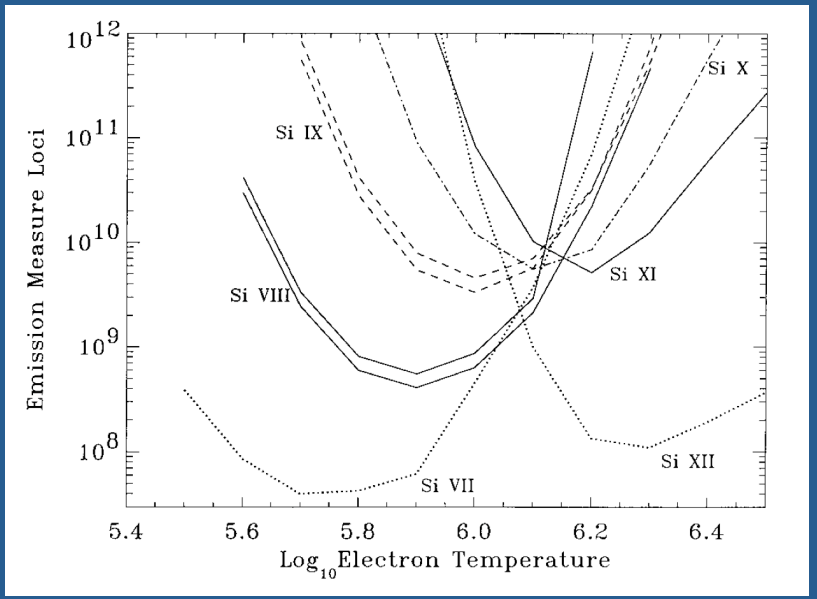
- This has come back in vogue during SOHO era
- For each line an inverted G(T) function is plotted
  - curve shows isothermal emission measure required to explain line intensity



MacPherson & Jordan (1999, MNRAS) [CDS, SUMER]

Isothermal plasmas

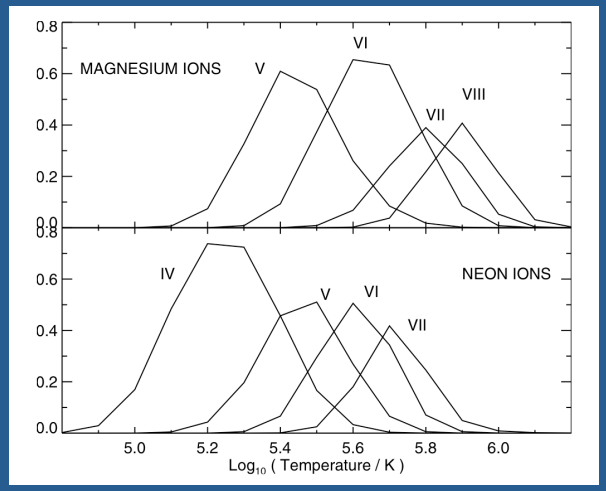
- The EM loci method is valuable for identifying isothermal plasmas
- If the curves all meet at the same (*T,EM*) point, then the plasma is isothermal
- Quiet Sun plasma above limb is isothermal with T=1.2 x 10^6 K



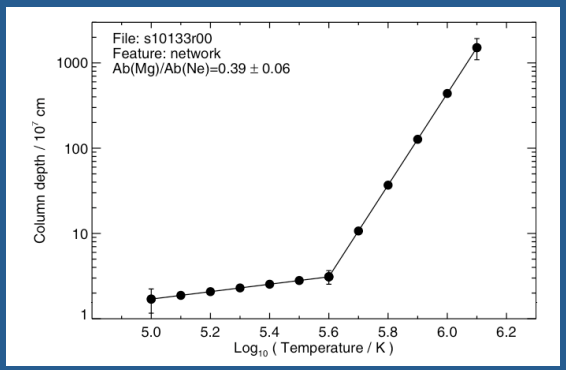
Feldman et al. (1999, ApJ) [SUMER]

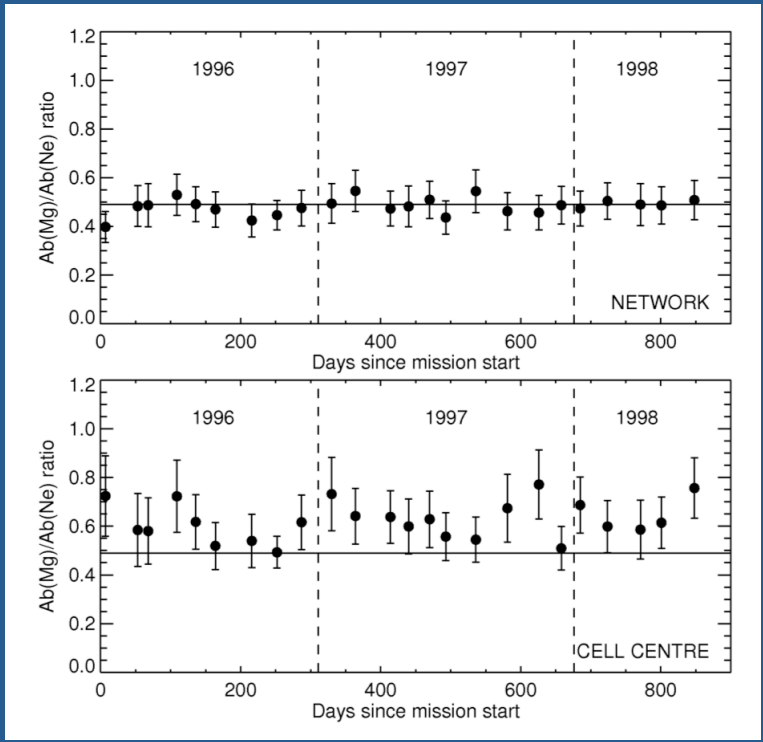
Element abundances

- CDS gives access to overlapping sequences of Mg and Ne ions in the upper transition region
- No evidence for FIP effect in quiet Sun was found by Young (2005, 2006)



FIP(Mg)=7.6 eV
FIP(Ne)=21.6 eV

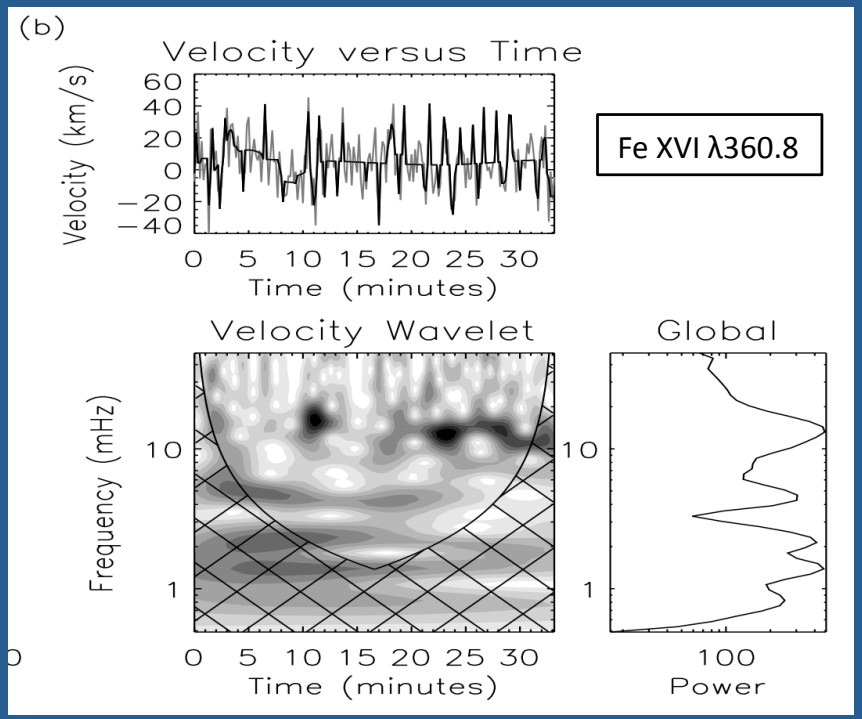




Young (2005, A&A)
Young (2006, Proc. SOHO 17)

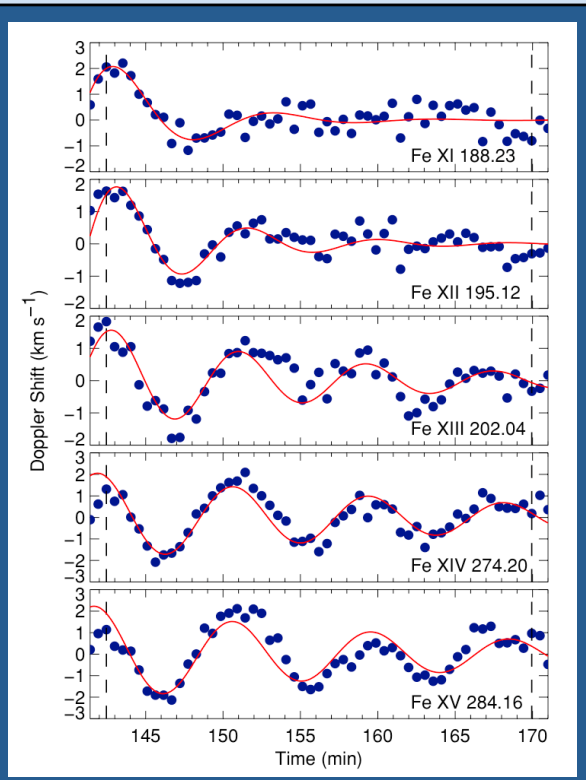
Coronal seismology

- Performing ‘sit-and-stare’ observations allows emission line parameters to be studied as function of time
- A plethora of oscillation results have appeared from imaging and spectroscopic instruments during the SOHO era



Fe XVI λ360.8

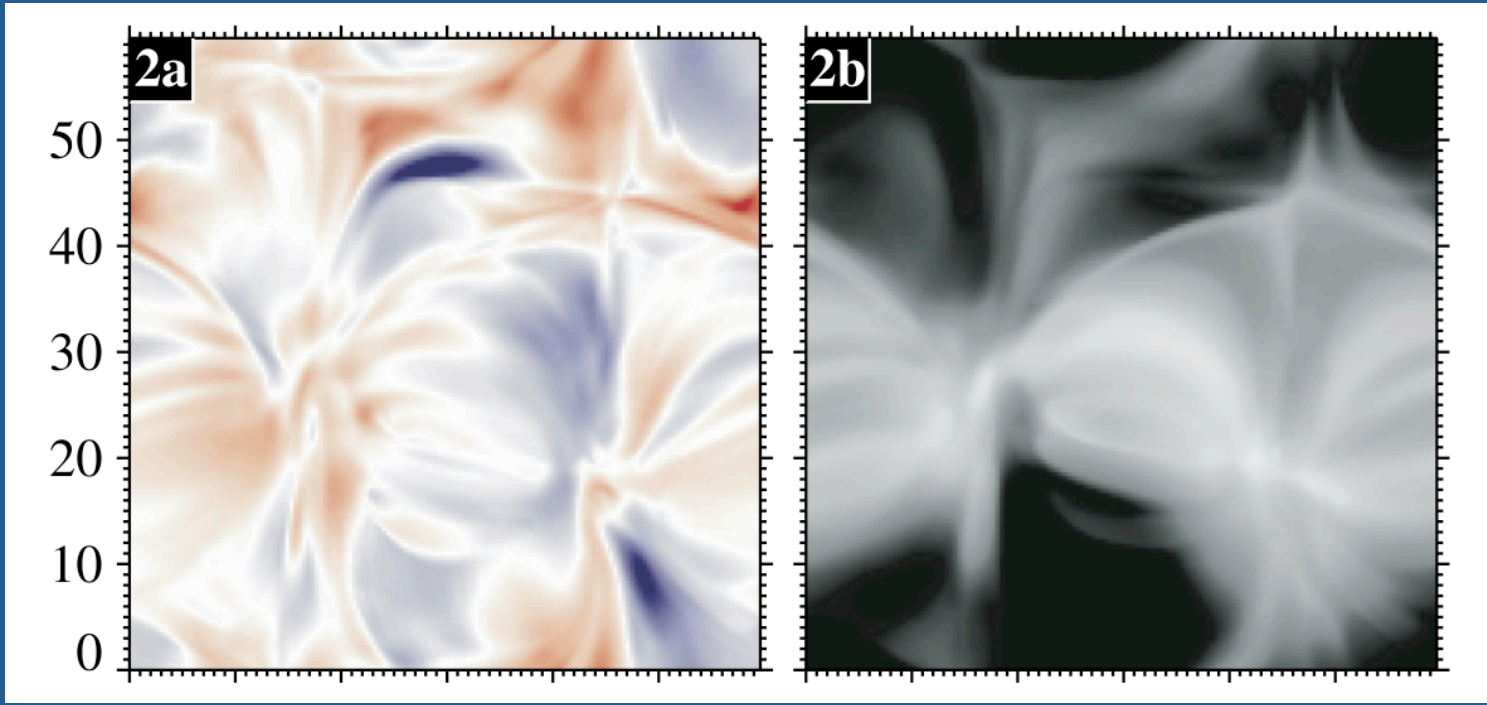
O’Shea et al. (2001, A&A) [CDS]



Mariska & Muglach (2010, ApJ) [EIS]

Forward Modelling

- Theory and observations have been brought closer together through forward modelling
- i.e., use model's density and temperature values to predict intensity and velocity of emission lines
- the availability of CHIANTI has been critical for this work

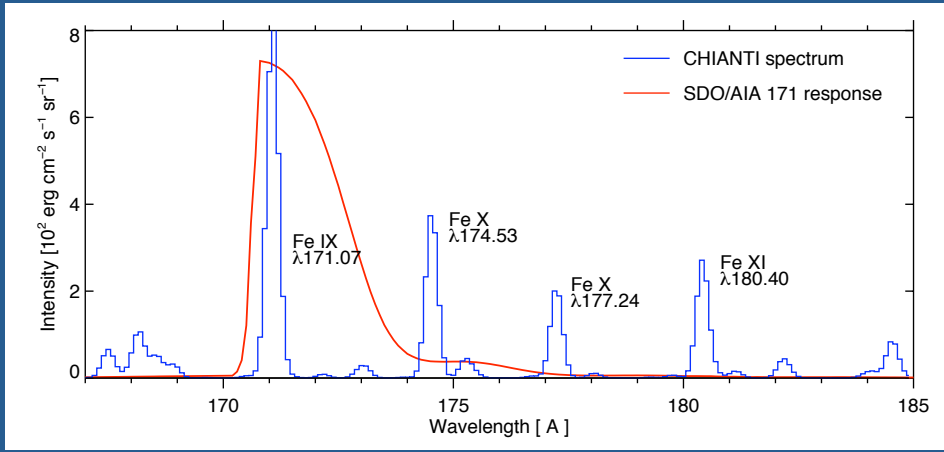


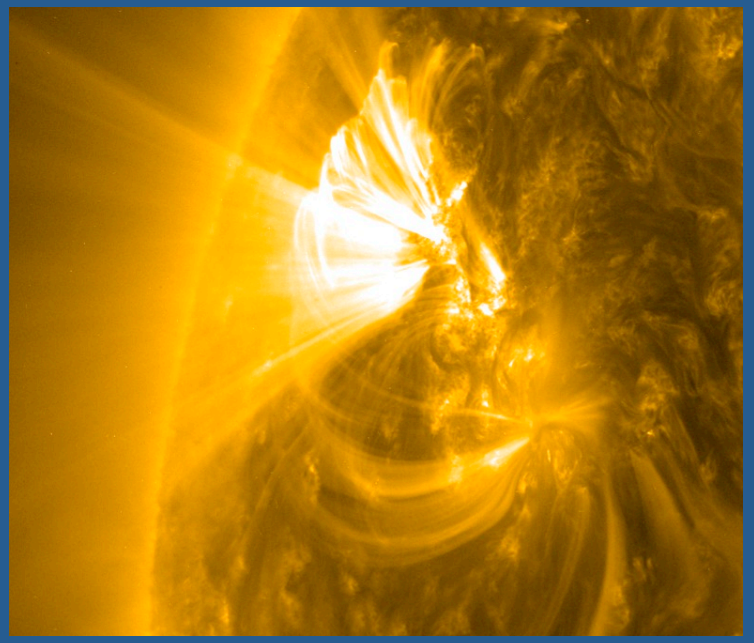
Predicted velocity and intensity map for Mg X λ624.9 from Peter et al. (2006, ApJ)

EUV imaging

- EUV imagers (SOHO/EIT, TRACE, STEREO/EUVI, SDO/AIA) have had a major impact on solar physics
- Narrow passbands allow (almost) monochromatic imaging in EUV emission lines
- Diagnostics: temperature, emission measure

- Spectroscopy important for modelling instrument response





SDO/AIA 171 channel

Where next?

My list of goals for future UV spectrometers:

1. Simultaneous coverage of strong lines from chromosphere to corona
2. Accurate wavelength calibration for EUV coronal lines
3. 0.1” imaging capability
4. Higher spectral resolution for resolving structure in line profiles

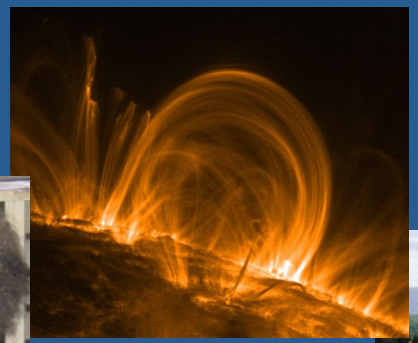
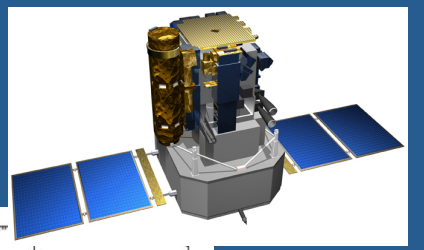
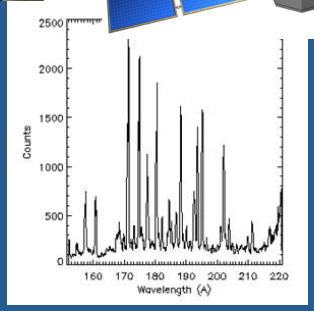
<u>Ultimate dream</u>

Simultaneous 2D imaging and high-resolution spectroscopy

Advances in instrumentation must go hand-in-hand with improvements in atomic data

Summary

The SOHO era has seen a big growth in the use of UV spectroscopy

- Easy access to large quantities of observational data (CDS, SUMER, EIS)
- Easy access to high quality atomic data and analysis software (CHIANTI)
- Software and documentation freely available over the internet

Helen has played an important role in this growth by ensuring that instrument teams, atomic physicists, theorists and spectroscopists work towards providing great data for the solar community.