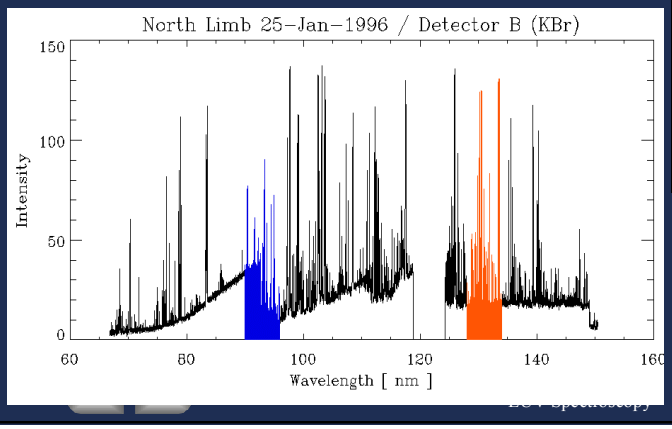
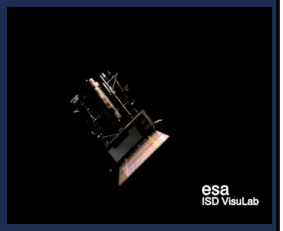
Space Instrumentation (9)

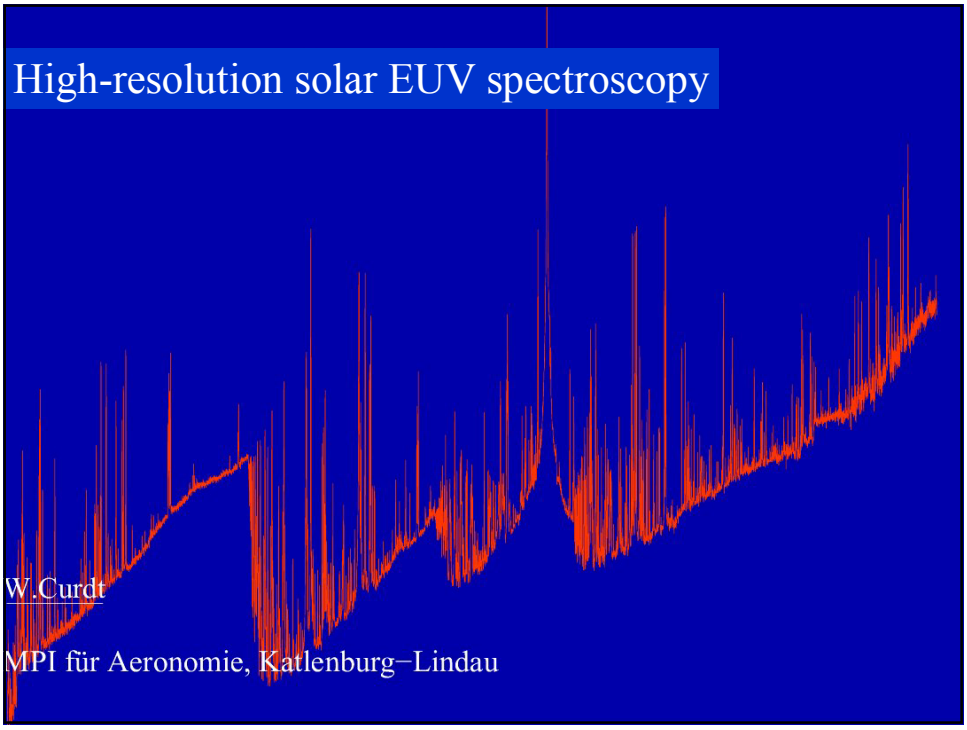
Lectures for the IMPRS June 23 to June 27 at MPAe Lindau
Compiled/organized by Rainer Schwenn, MPAe
supported by Drs. Curdt, Gandorfer, Hilchenbach, Hoekzema, Richter, Schühle

Thu, 26.6., 14:00 Solar EUV spectroscopy (Curdt)





High-resolution solar EUV spectroscopy



W.Curdt

MPI für Aeronomie, Katlenburg–Lindau

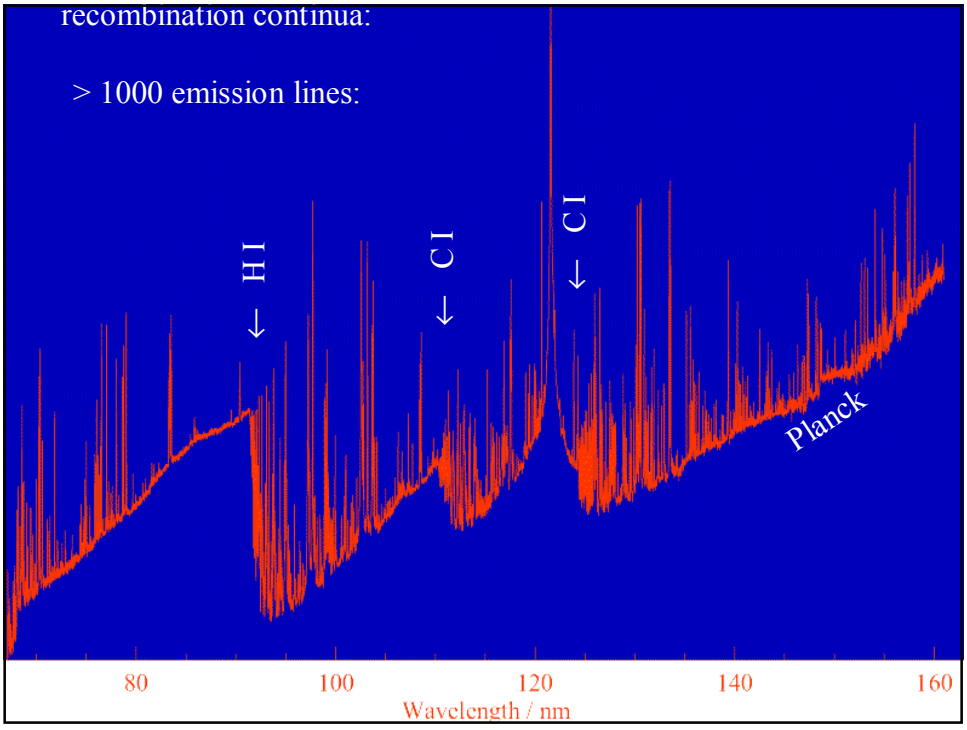
Outline

- motivation
- instrumental aspects
- scientific methods
- observation examples
- outlook

EUV Spectroscopy

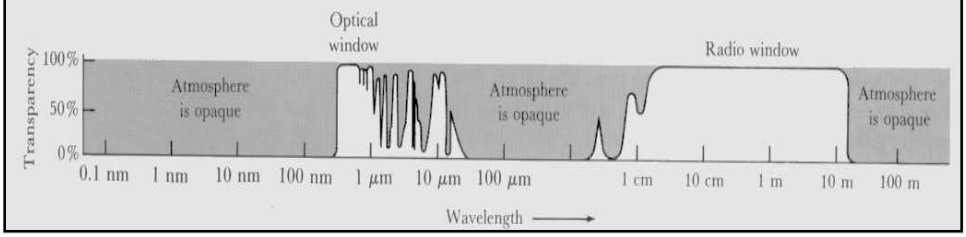
recombination continua:

> 1000 emission lines:



UV range classification

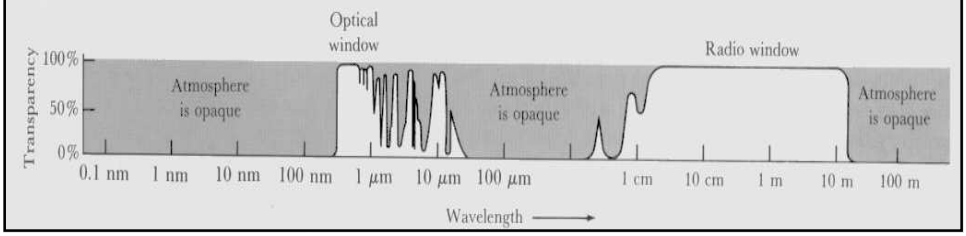
- Near UV λ > 300 nm
- Mid UV 200 nm < λ < 300 nm
- Extreme UV 100 nm < λ < 200 nm
- Vacuum UV 10 nm < λ < 200 nm
- soft x-ray 1 nm < λ < 30 nm



UV range classification

- Near UV λ > 300 nm

Absorption by ozone and other molecules !



Historical overview

- 1950 Bragg-crystal spectrometers
- 1962 OSO armada
- 1973 Apollo Telescope Mount
- 1975 HRTS, 8 rocket flights
- 1985 HRTS, Spacelab 2
- 1996 SOHO-CDS
- 1996 SOHO-SUMER

EUV Spectroscopy

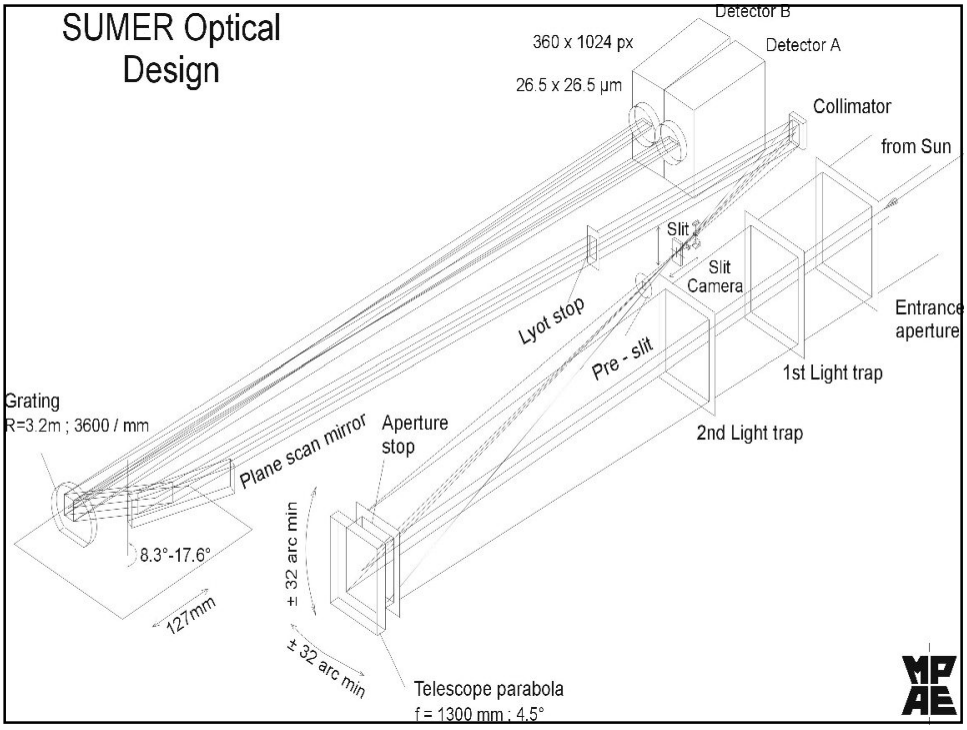
Performance characteristic

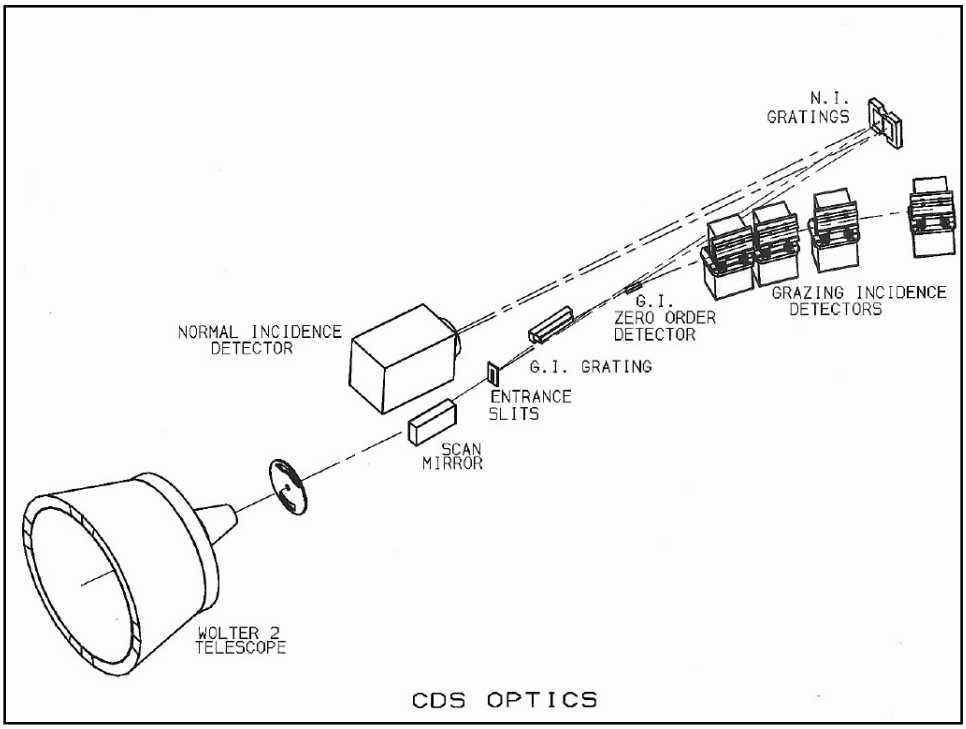
	CDS	SUMER
wavelegth range, Å	308-381 (NI)	790-1608 (1)
	513-633	465-804 (2)
	151-221 (GI)	
	256-338	
	393-493	
	656-785	
spatial resolution	4 - 8	1.2
spectral resolution, km/s	10	2
temporal resolution, s	10	10

EUV Spectroscopy

Instrumental aspects

- **Spectroscope:**
  - telescope
  - slit
  - dispersive element
  - 2D detector
- **infrastructure**
  - to bring the instrument into space
  - to bring the data back to Earth





Telescope primary mirror

- size determines spatial resolution
- size ~ photon input ⇒ temporal resolution
- figure defines PSF
- micro roughness defines scattered light level
- needs pointing mechanism
- optical surface:
  - λ > 120 nm ⇒ Al/MgF2
  - λ > 50 nm ⇒ Si C
  - λ < 50 nm grazing incidence (Wolter) or multilayer coating

EUV Spectroscopy

Telescope slit

- **Slit width limits spatial resolution**
- **slit width limits spectral resolution**
- **slit: loss of >99% of photons**
  - slitless spectroscopes (strong lines, filters)
  - slot spectroscopes (wide slit)
  - raster scans
  - drift scans

EUV Spectroscopy

Telescope collimator

- **Makes parallel light (classical design)**
- **defines magnification (pixel adjustment)**
- **folds the light beam (compactness)**

EUV Spectroscopy

Spectroscope grating

- **Bragg crystal systems**
- **holographic gratings**
- **ruled gratings**
- **variable line space technique**
  - future 3 reflection designs
  - future 2 reflection designs

EUV Spectroscopy

Instrument detector(s)

- **Films**
- **MCP detectors**
  - multianode systems (MAMA)
  - time delay systems (XDL)
- **CCDs**
  - back-illuminated CCDs
  - intensified CCDs
- **APS sensors**
- **BOLD detectors**

EUV Spectroscopy

Scientific methods

- line selection
- line shifts / Doppler flows
- line widths / line shape
- plasma diagnostics / line ratios
- raster scans
- drift scans
- abundance measurements / FIP effect
- radiance / irradiance
- atomic physics

EUV Spectroscopy

Line emission

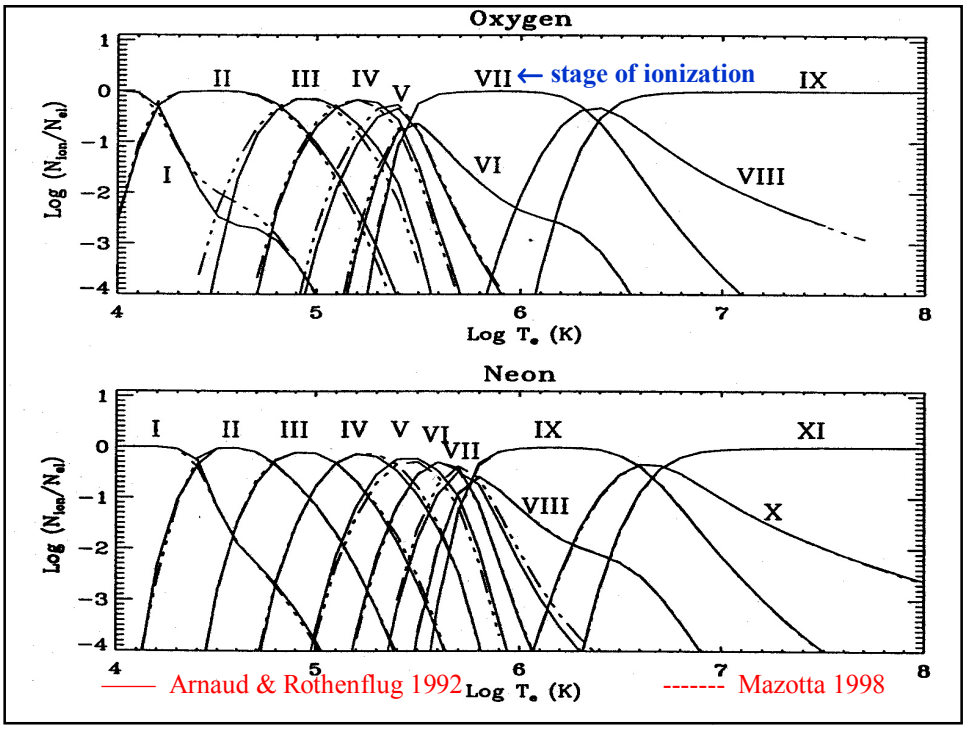
$$P(\lambda) = \int \frac{hc}{\lambda} \quad A_{ul} \quad N_u \quad dV$$

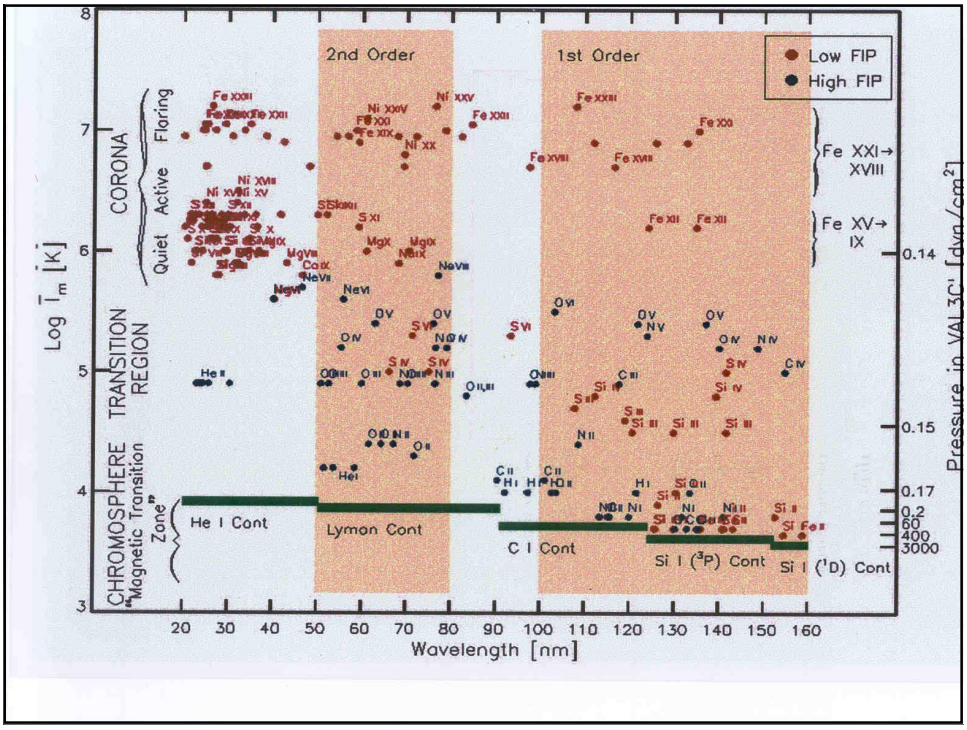
A_{ul} upper/lower level transition probabability

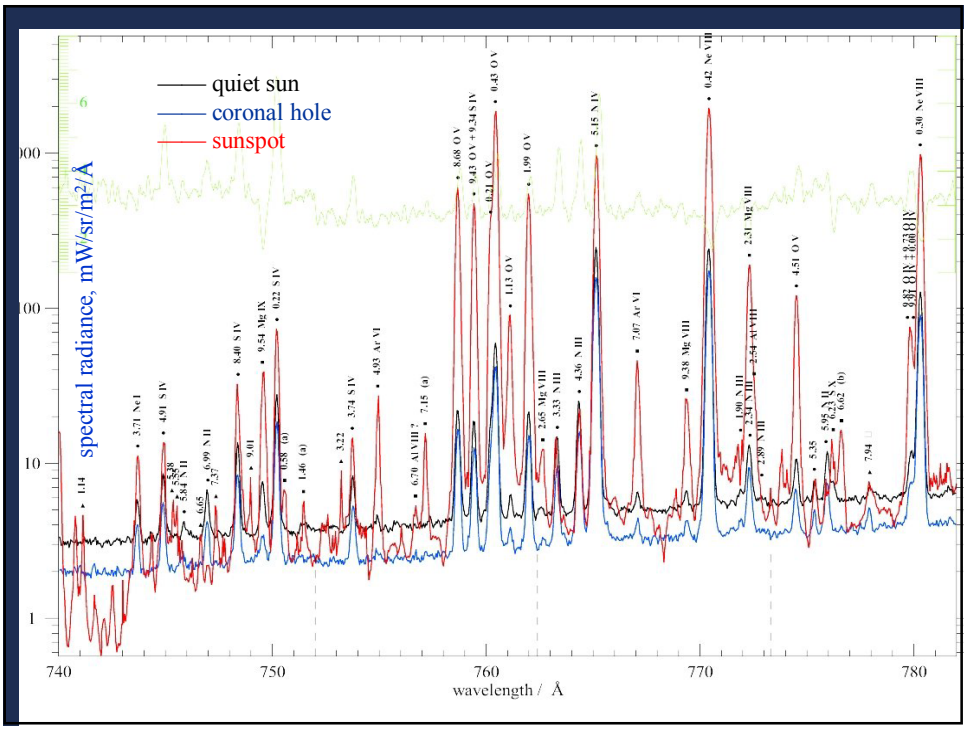
$$Nu = \frac{Nu(X^{+p})}{N(X^{+p})} \quad \frac{Nu(X^{+p})}{N(X)} \quad \frac{N(X)}{N(H)} \quad \frac{N(H)}{Ne} \quad Ne$$

excited level population | degree of ionization | elemental abundance | hydrogen abundance

EUV Spectroscopy


Oxygen
Log (N_ion/N_el)
I
II
III
IV
V
VI
VII ← stage of ionization
VIII
IX
Log T_e (K)
Neon
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
Log (N_ion/N_el)
Log T_e (K)
—— Arnaud & Rothenflug 1992
------- Mazotta 1998


2nd Order
1st Order
Low FIP
High FIP
Fe XXI→ XVIII
Fe XV→ IX
CORONA
Flaring
Active
Quiet
TRANSITION REGION
CHROMOSPHERE
"Magnetic Transition Zone"
He I Cont
Lyman Cont
C I Cont
Si I (³P) Cont
Si I (¹D) Cont
Log T_m [K]
Pressure in VAL 3C' [dyn/cm²]
Wavelength [nm]



Line shape

- emission profile $\Psi(\lambda)$
  $\Psi(\lambda) = \Psi(\lambda)_{nat} * \Psi(\lambda)_{coll} * \Psi(\lambda)_{th} * \Psi(\lambda)_{NT}$
- Optically thin emission lines are Gaussian
- $\Delta\lambda_D = \lambda_0/c\ (2kT/m + \xi^2)^{1/2}$
  ξ non-thermal velocity (turbulence)

EUV Spectroscopy

Line ratios

$P_{ul}(\lambda) \approx N_e^2$

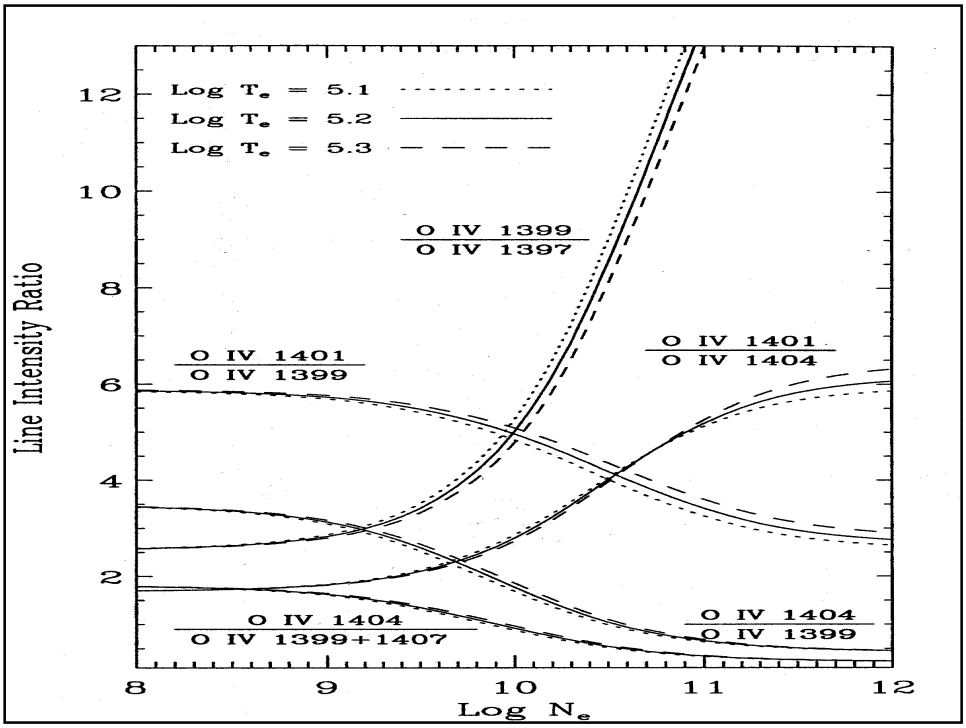
or

$P_{ul}(\lambda) \approx N_e$ metastable levels

N_e diagnostics

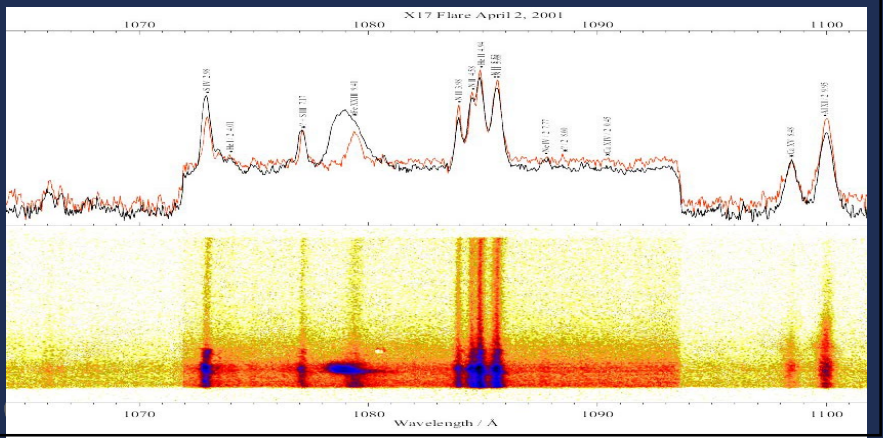
T_e diagnostics

EUV Spectroscopy

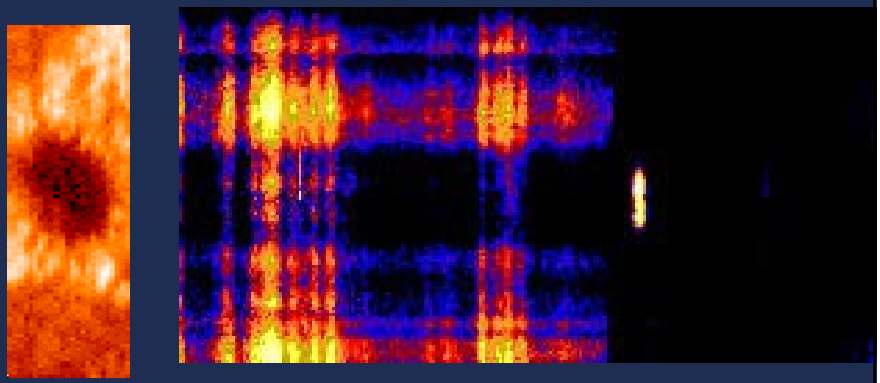


Doppler flows

- $\Delta\lambda / \lambda = v / c$
- Hires spectroscopes can resolve 1- 2 km/s

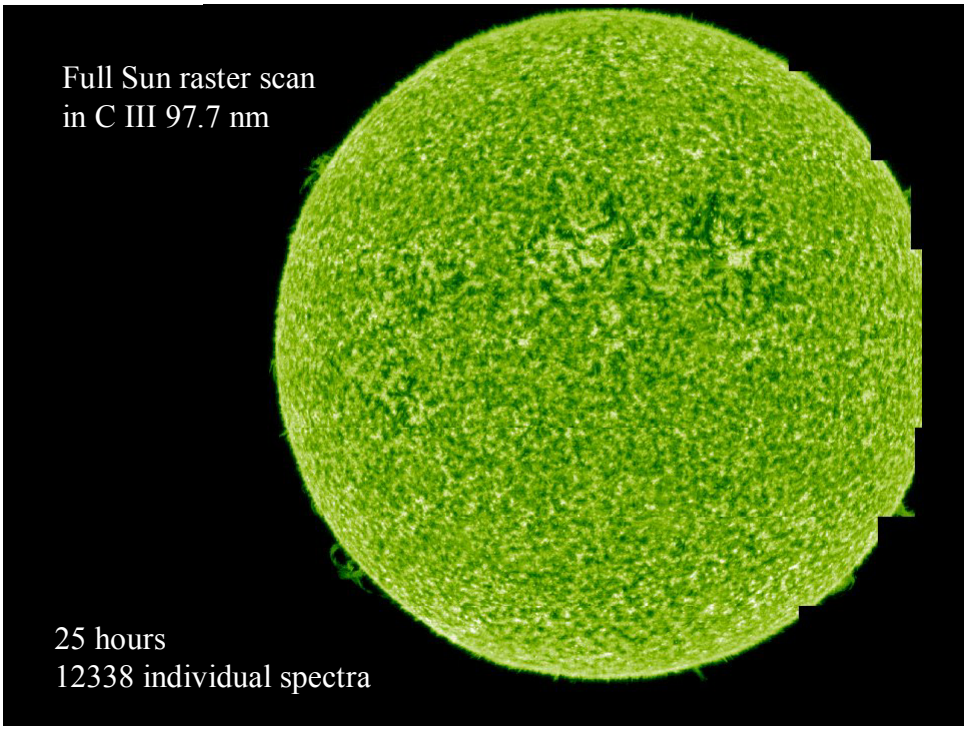


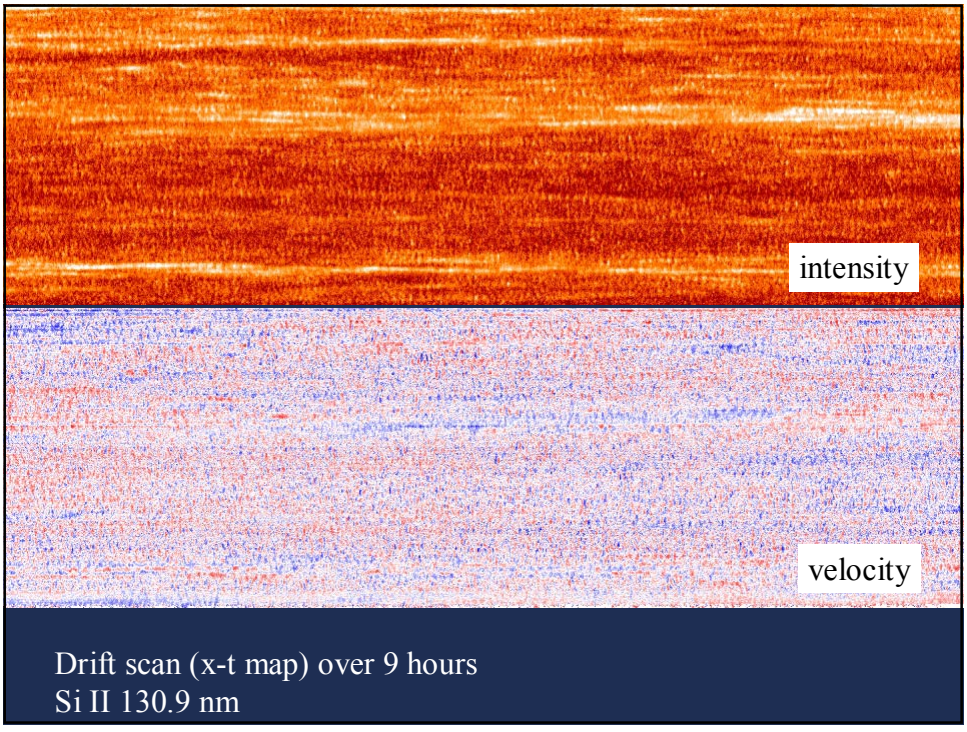
Sunspot onbserved on Mar 18, 1999

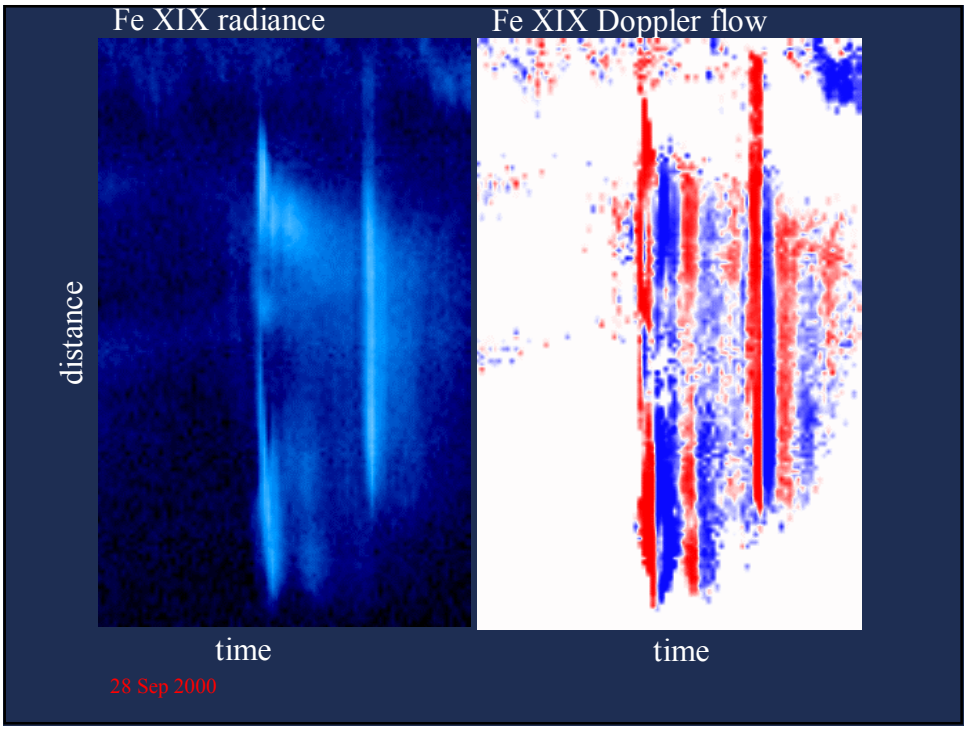


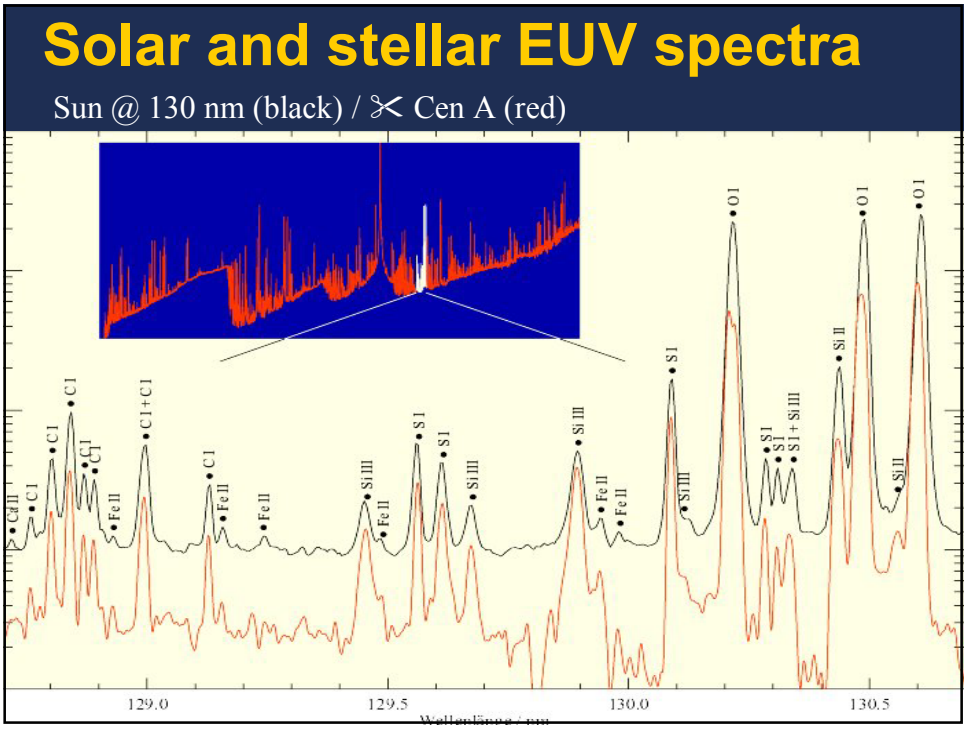
Raster scan in the continuum @ 1478 Å

Spectrum around 1163 Å with strong H_2 fluorescence emision


Full Sun raster scan
in C III 97.7 nm
25 hours
12338 individual spectra


intensity
velocity
Drift scan (x-t map) over 9 hours
Si II 130.9 nm


Fe XIX radiance
Fe XIX Doppler flow
distance
time
time
28 Sep 2000


Solar and stellar EUV spectra
Sun @ 130 nm (black) / ✂ Cen A (red)
129.0
129.5
130.0
130.5

Outlook

- SUMER and CDS still in operation
- Solar B
- Solar orbiter
- SMEX proposals under evaluation