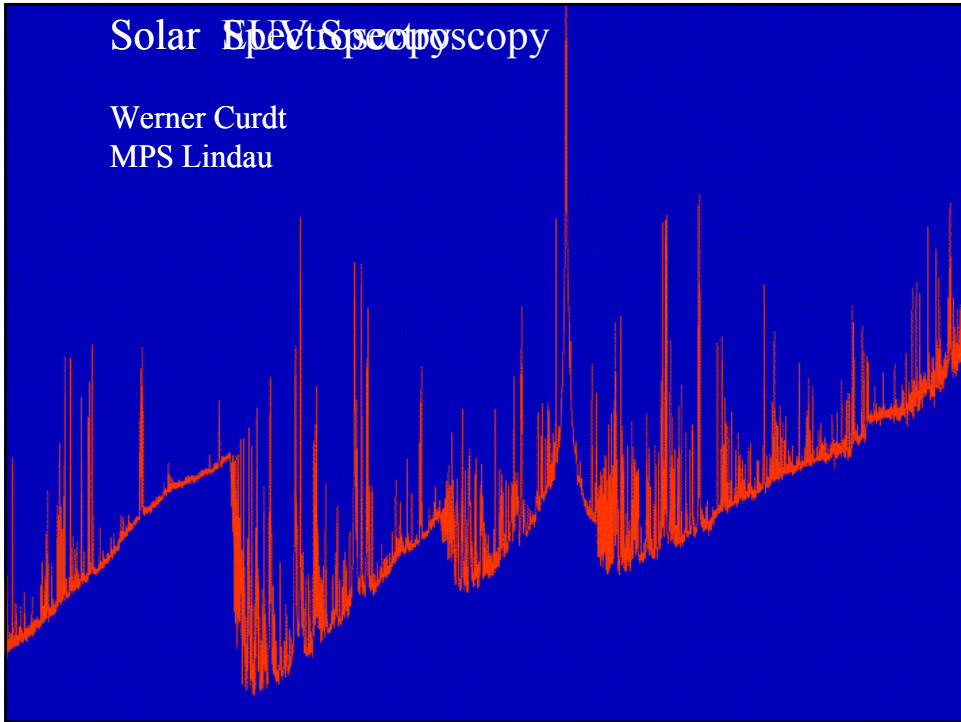


Solar EUV Spectroscopy

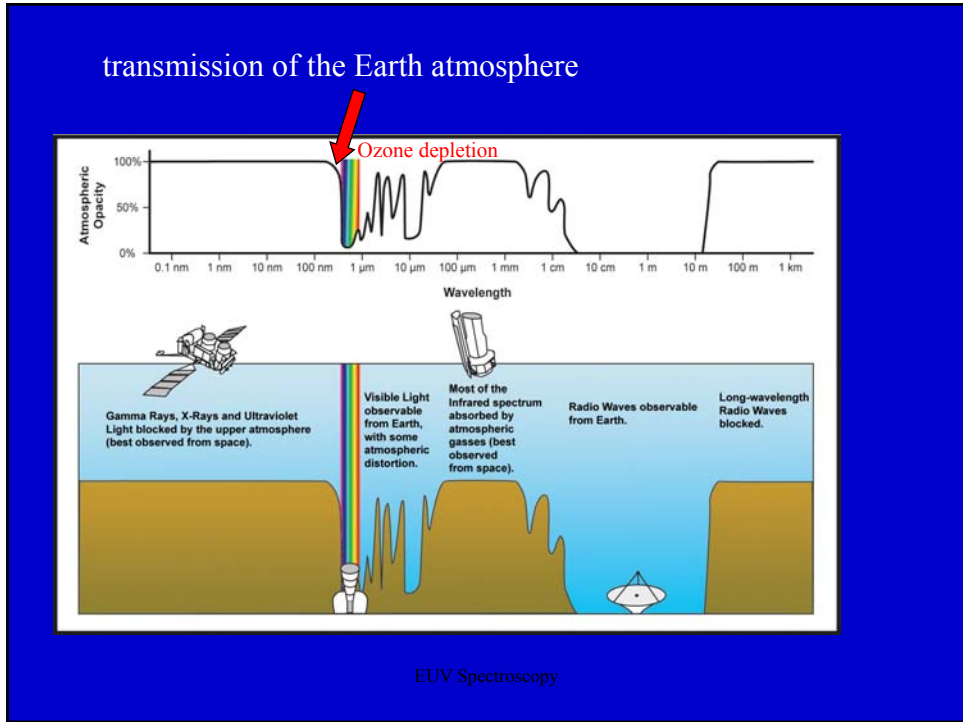
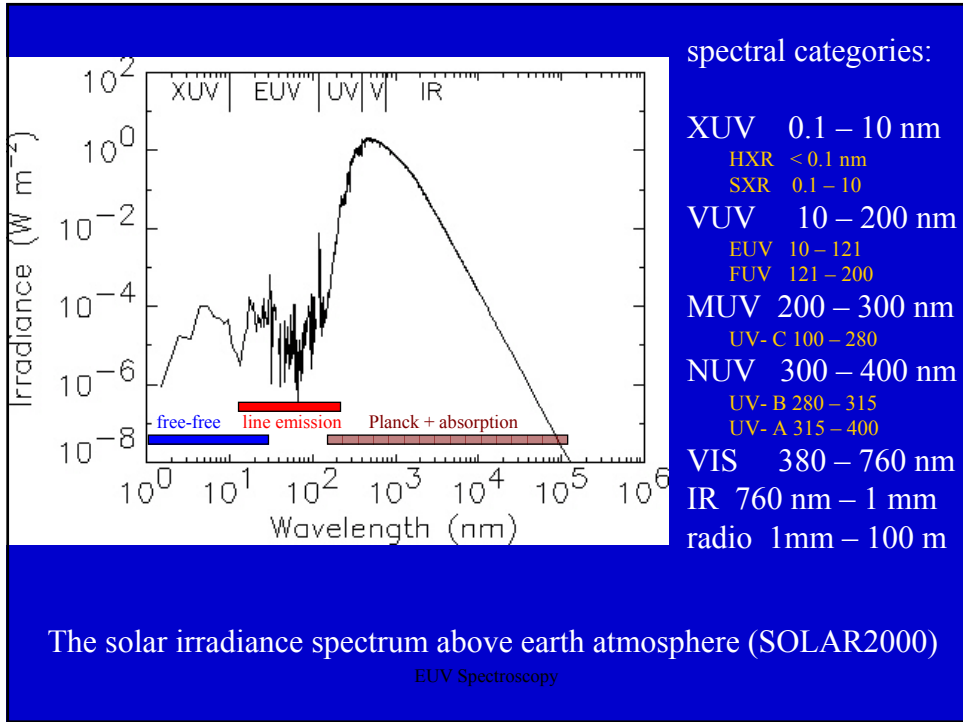
Werner Curdt
MPS Lindau



Outline

- motivation
 - the Sun's electromagnetic spectrum
 - spectroscopic methods
 - observational examples
- instrumental aspects
 - optical design
 - detectors
 - others
- highlights and outlook

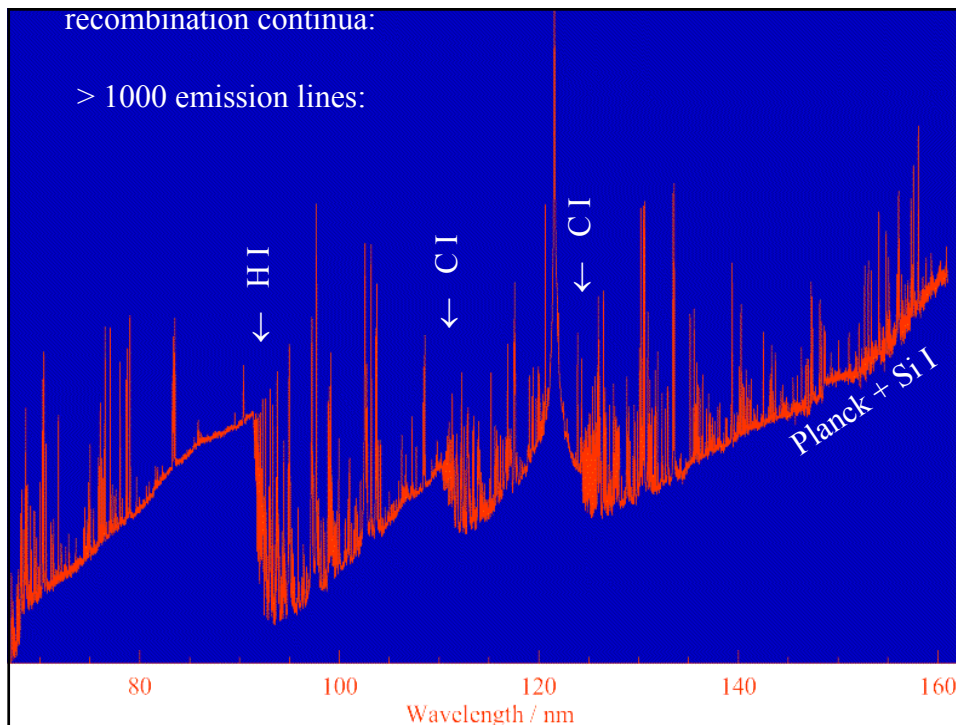
EUV Spectroscopy

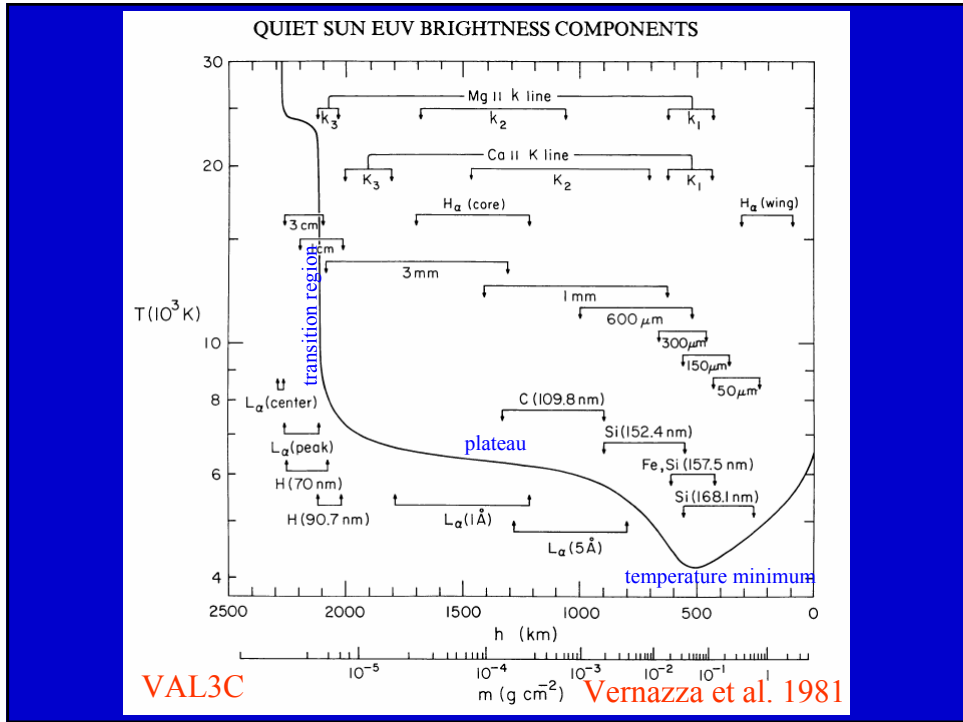
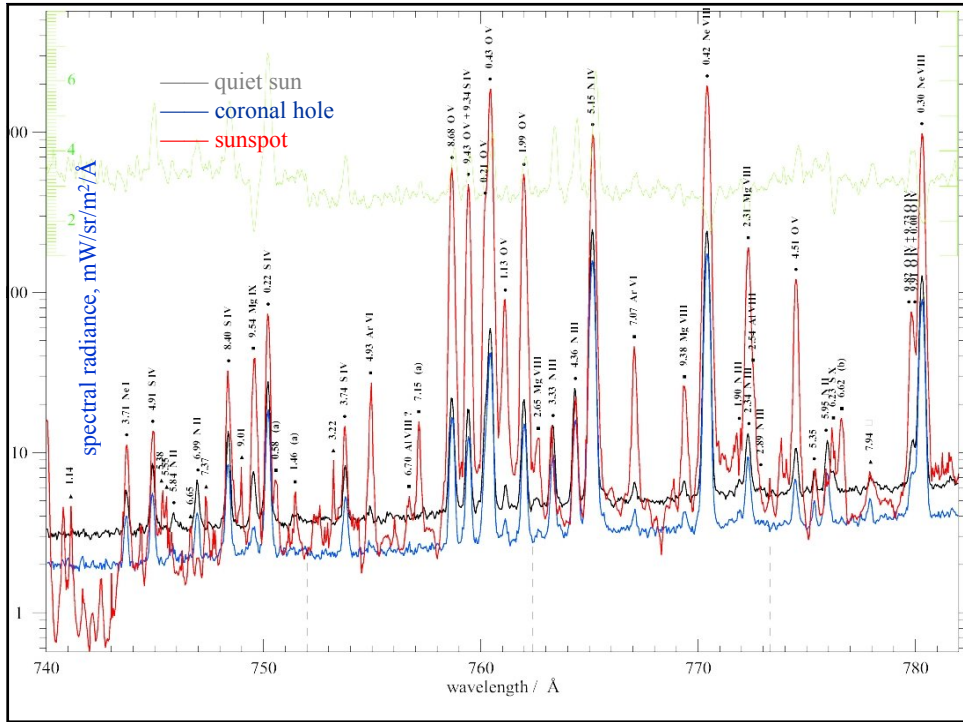


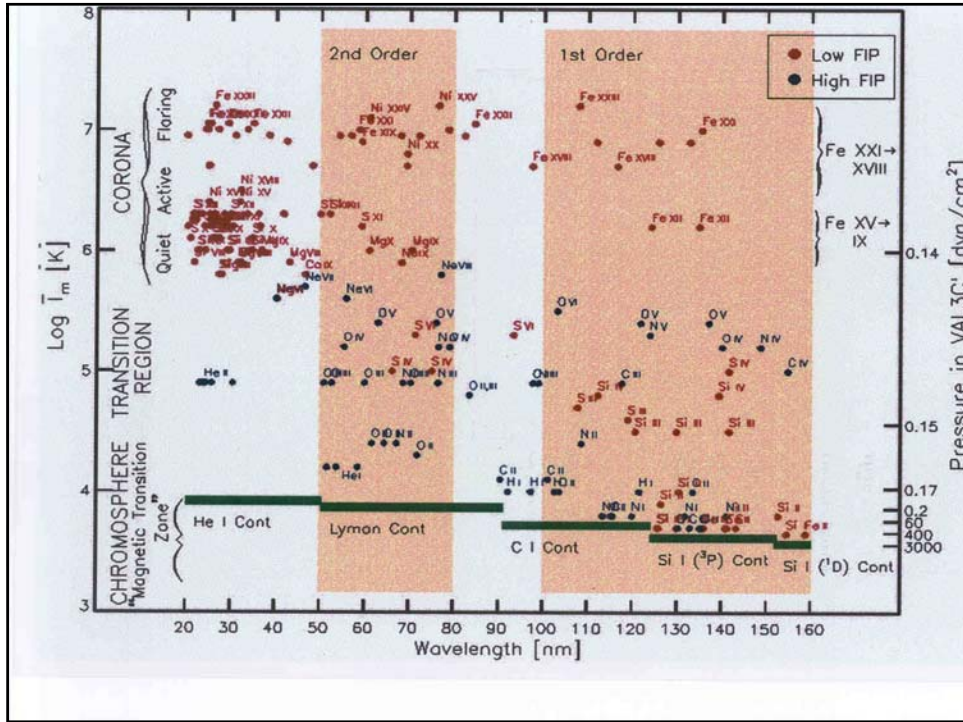
Spectroscopic methods

- line identification / 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

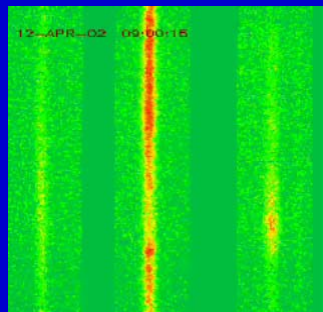






Doppler flows

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



Si III Ca X Fe IX
EUV Spectroscopy

Line emission

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

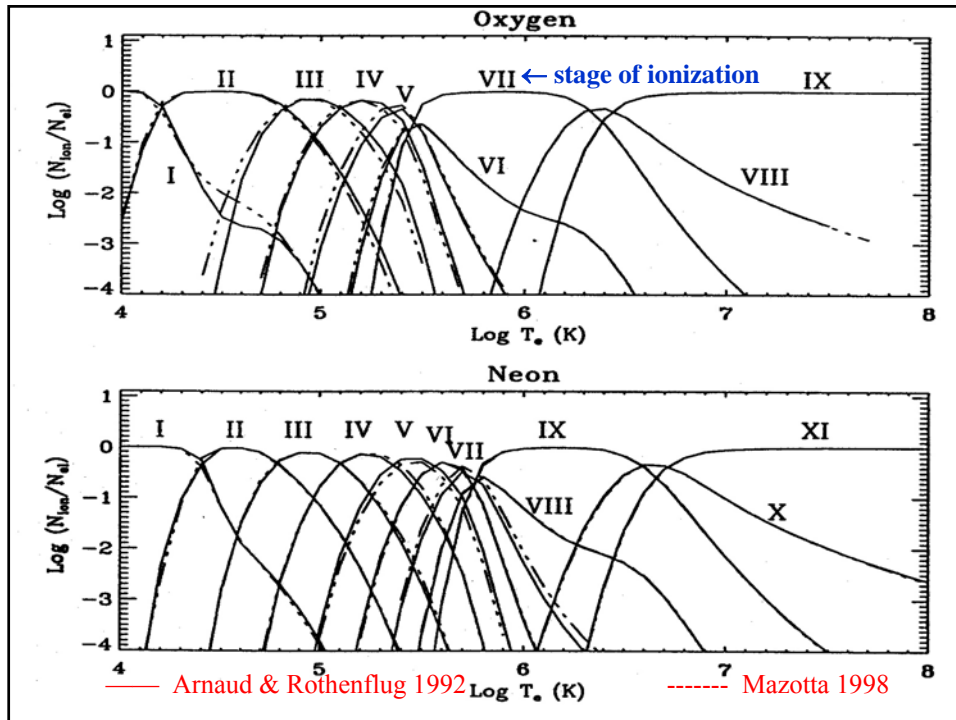
A_{ul} : upper/lower level transition probability

$$N_u = \frac{N_u(X^{+P})}{N(X^{+P})} \frac{N_u(X^{+P})}{N(X)} \frac{N(X)}{N(H)} \frac{N(H)}{N_e} N_e$$

excited level population degree of ionization elemental abundance hydrogen abundance

Chianti
ADAS
NIST

EUV Spectroscopy



Line shape

- emission profile $\Psi(\lambda)$

$$\Psi(\lambda) = \Psi(\lambda)_{\text{nat}} * \Psi(\lambda)_{\text{coll}} * \Psi(\lambda)_{\text{th}} * \Psi(\lambda)_{\text{NT}}$$

- Optically thin emission lines are Gaussians

- $\Delta\lambda_D = \lambda_0/c (2kT/m + \xi^2)^{1/2}$

ξ non-thermal velocity (turbulence)

EUV Spectroscopy

Line ratios

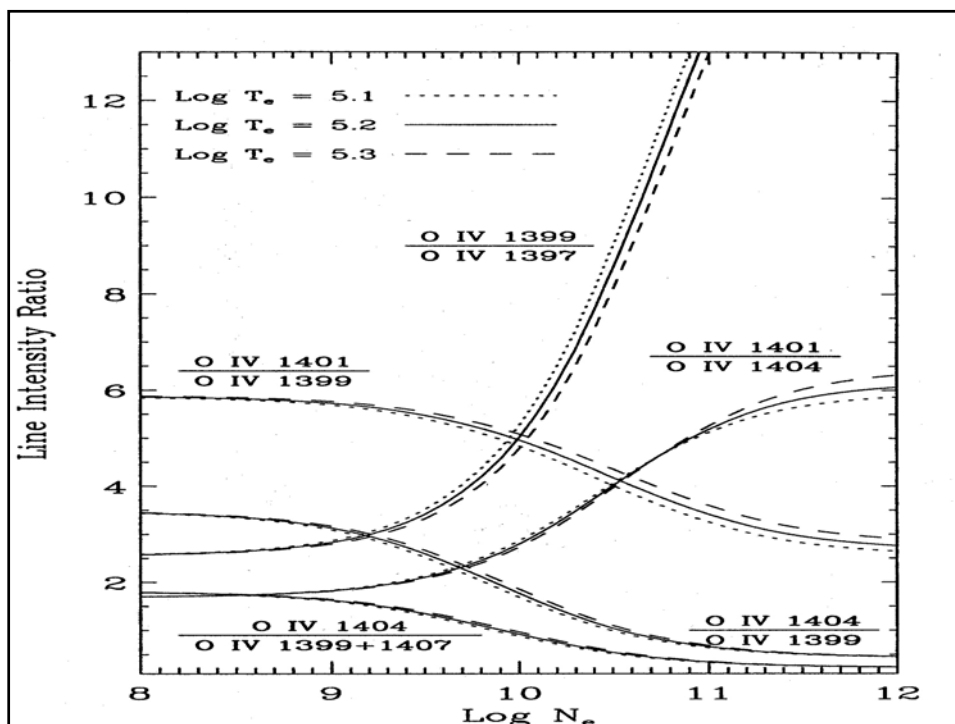
$$P_{ul}(\lambda) \approx N_e^2$$

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

N_e diagnostics

T_e diagnostics

EUV Spectroscopy



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
- 2006 Hinode-EIS
- 2015 SO EUS

EUV Spectroscopy

Performance characteristic

Coronal Diagnostic Spectrograph
 Solar Ultraviolet Measurement of Emitted Radiation
 EUV Imaging Spectrograph

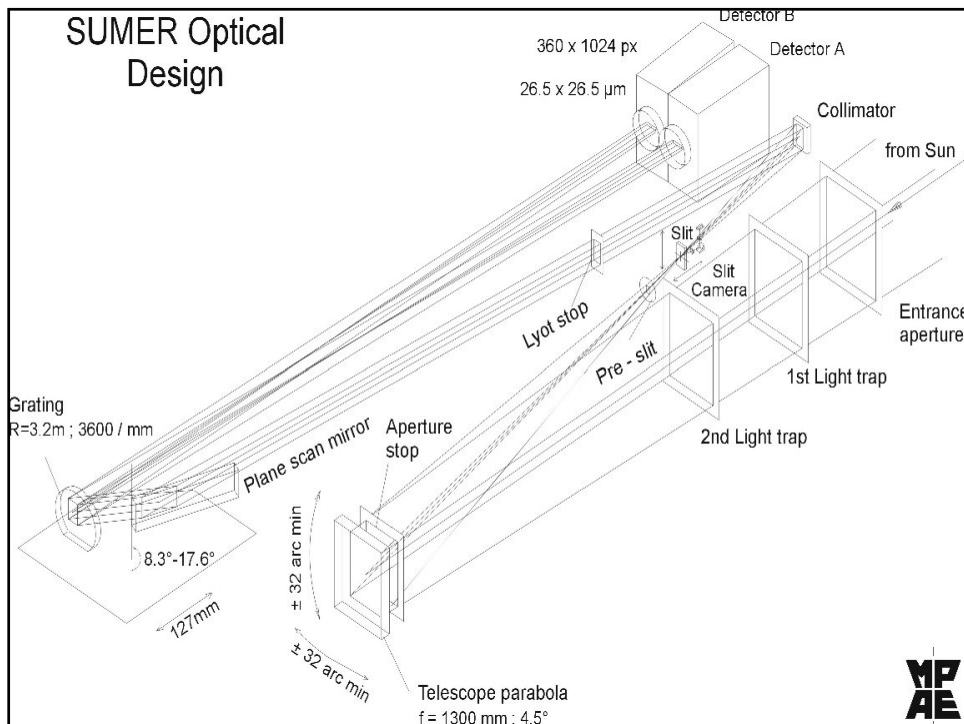
	CDS	SUMER	EIS
wavelegh range, Å	308-381 (NI)	790-1608 (1)	180 - 204 (A)
	513-633	465-804 (2)	240 - 290 (B)
	151-221 (GI)		
	256-338		
	393-493		
	656-785		
spatial resolution / "	4 - 8	1.2	1
spectral " / km/s	10	2	2-3
temporal " / s	10	10	1

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

EUV Spectroscopy



Telescope primary mirror

- size determines spatial resolution, λ/D
- size \sim photon input \Rightarrow temporal resolution
- figure defines PSF
- micro roughness defines scattered light level
- needs pointing mechanism
- optical surface:
 - $\lambda > 120 \text{ nm} \Rightarrow \text{Al/MgF}_2$
 - $\lambda > 50 \text{ nm} \Rightarrow \text{Si C}$
 - $\lambda < 50 \text{ nm}$ grazing incidence (Wolter) or multilayer coating

Telescope slit

- slit width limits photon input
- slit width limits spectral resolution
- slit: loss of >99% of photons
 - slitless spectroscopes (strong lines, filters)
 - slot spectroscopes (wide slit)
 - raster scans
 - drift scans (low temporal resolution)

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 (TVLS)
 - future 2 reflection designs

EUV Spectroscopy

Instrument detector(s)

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

EUV Spectroscopy

Telemetry issues

16 bit pixels
1 k x 1k
10 s

dynamical range
small and numerous
good time resolution

Example SUMER: $\frac{16 \text{ bit/px} \times 400\,000 \text{ bit}}{10 \text{ s}} \approx 500 \text{ kbit/s}$

Data selection

windows, binning

Data compression

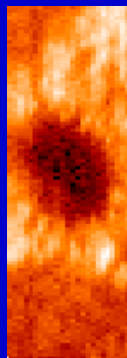
sqrt, JPEG, MPEG

Data reduction

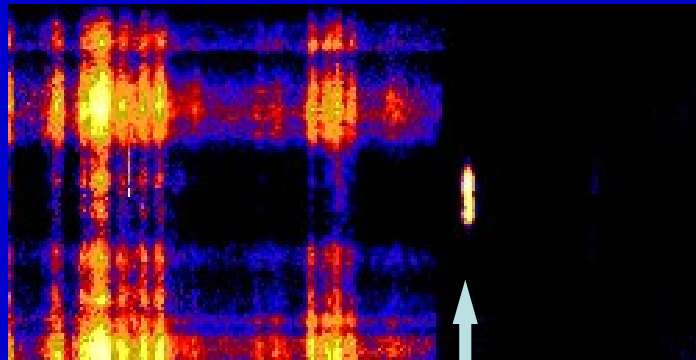
moments

EUV Spectroscopy

Sunspot onbserved on Mar 18, 1999

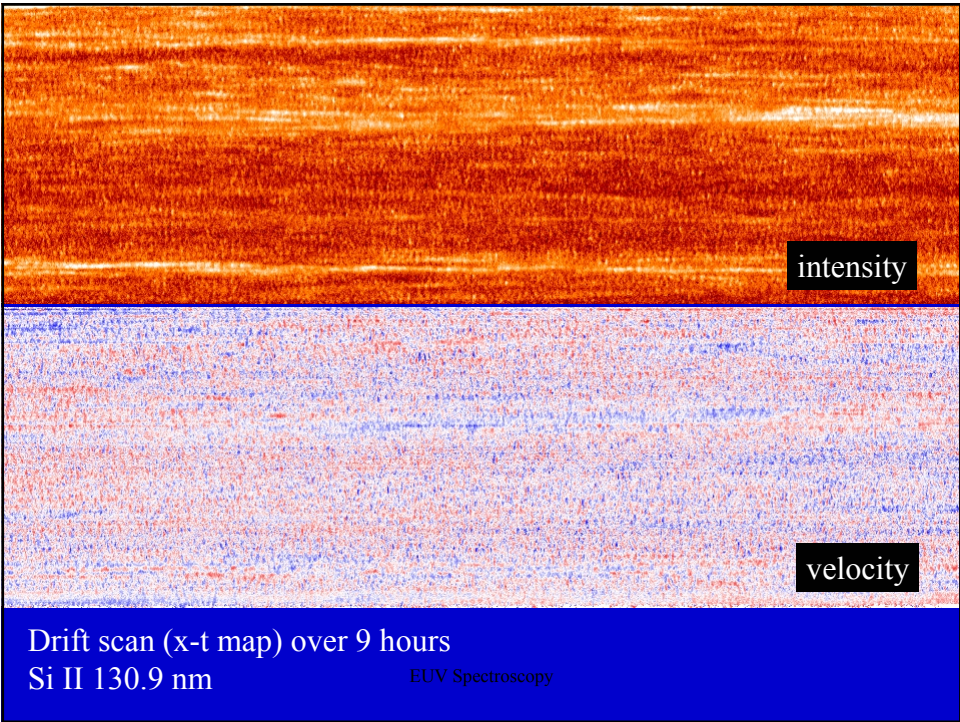
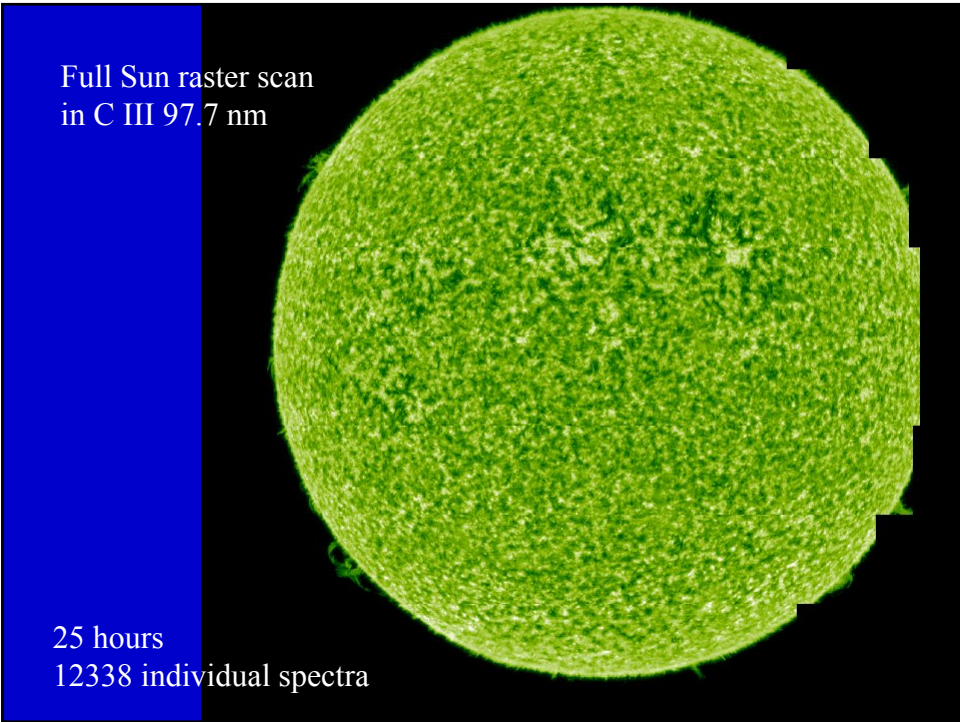


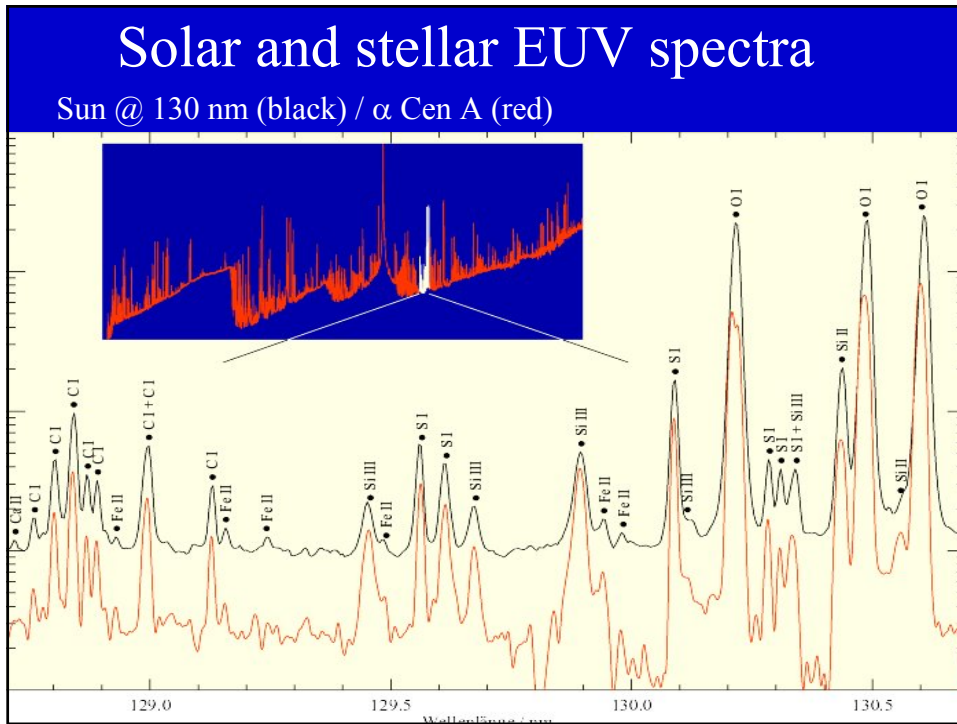
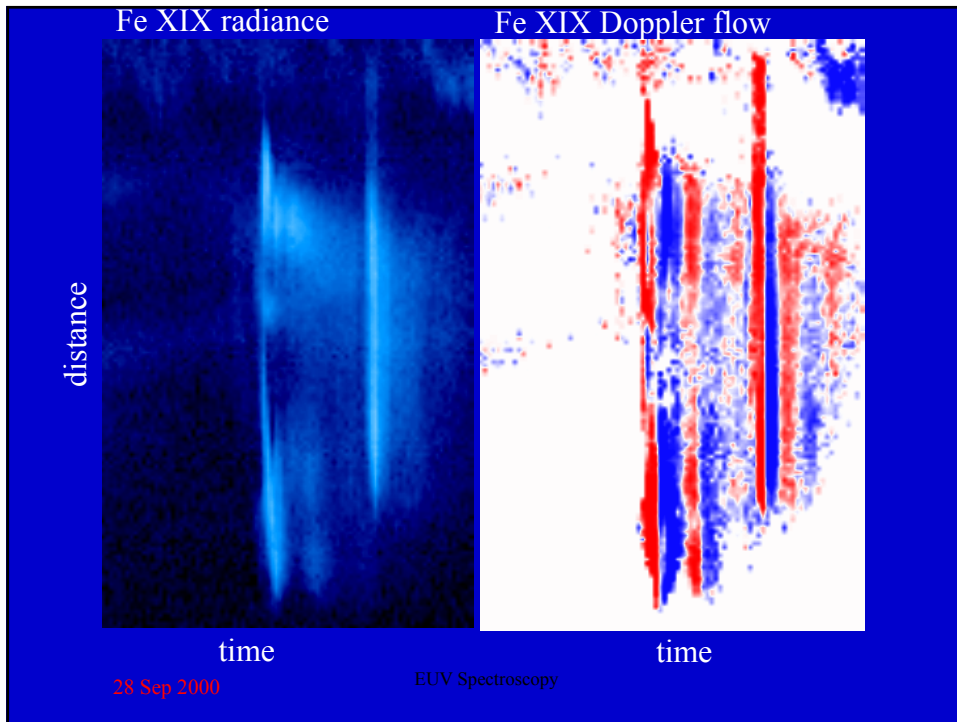
Raster scan in the
continuum @ 1478 Å



Spectrum around 1163 Å with
strong H₂ fluorescence emission

EUV Spectroscopy





Outlook

- SUMER and CDS still in operation
- HINODE EIS
- Solar orbiter EUS

EUV Spectroscopy

