SOHO / SUMER: data reduction and results

To be found in a separate PDF file

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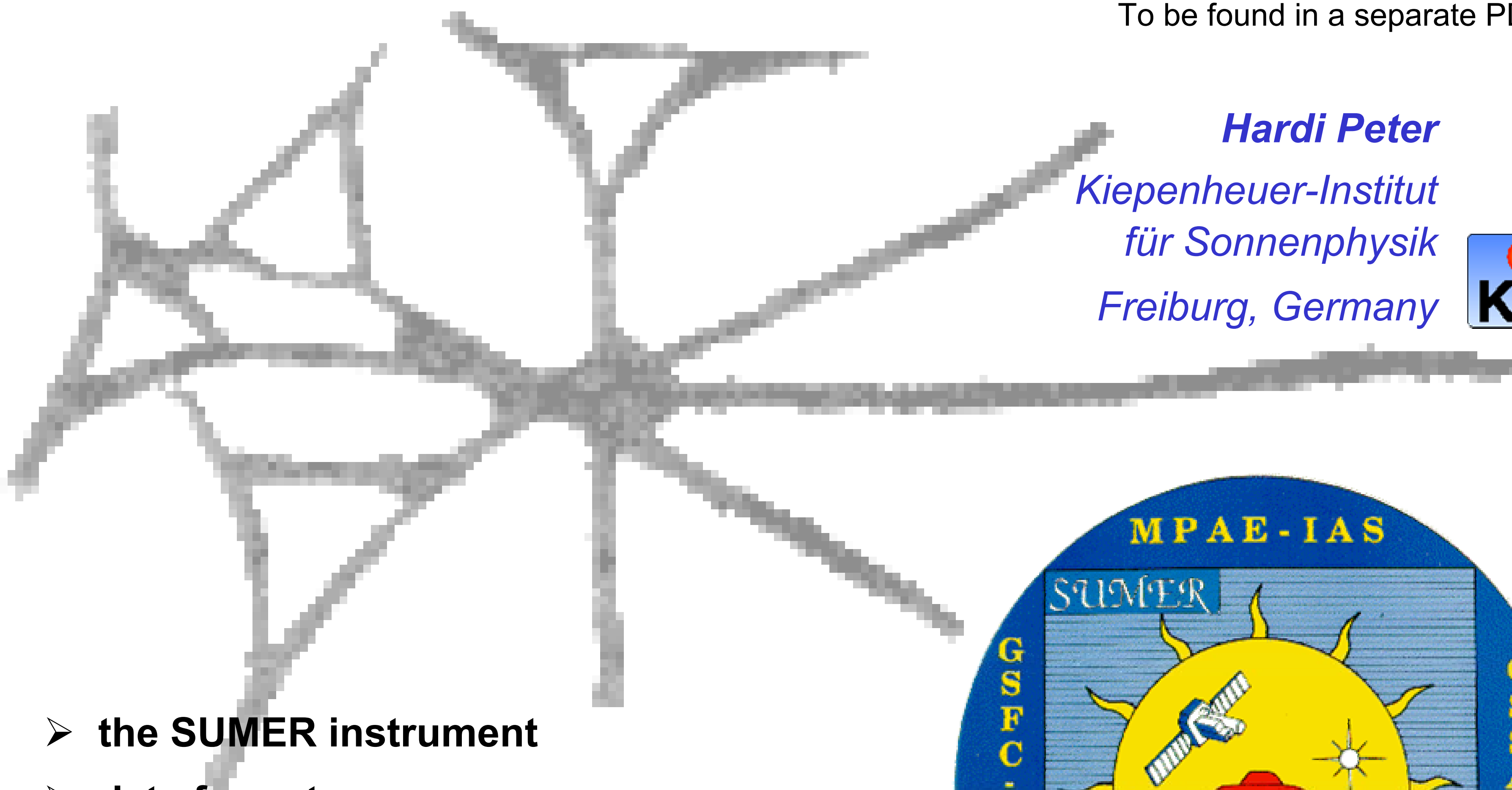

- **the SUMER instrument**
- **data formats**
- **data reduction: basics**
- **more details on Doppler shifts**
- **what SUMER is good at: some results**

Solar and Heliospheric Observatory / SUMER

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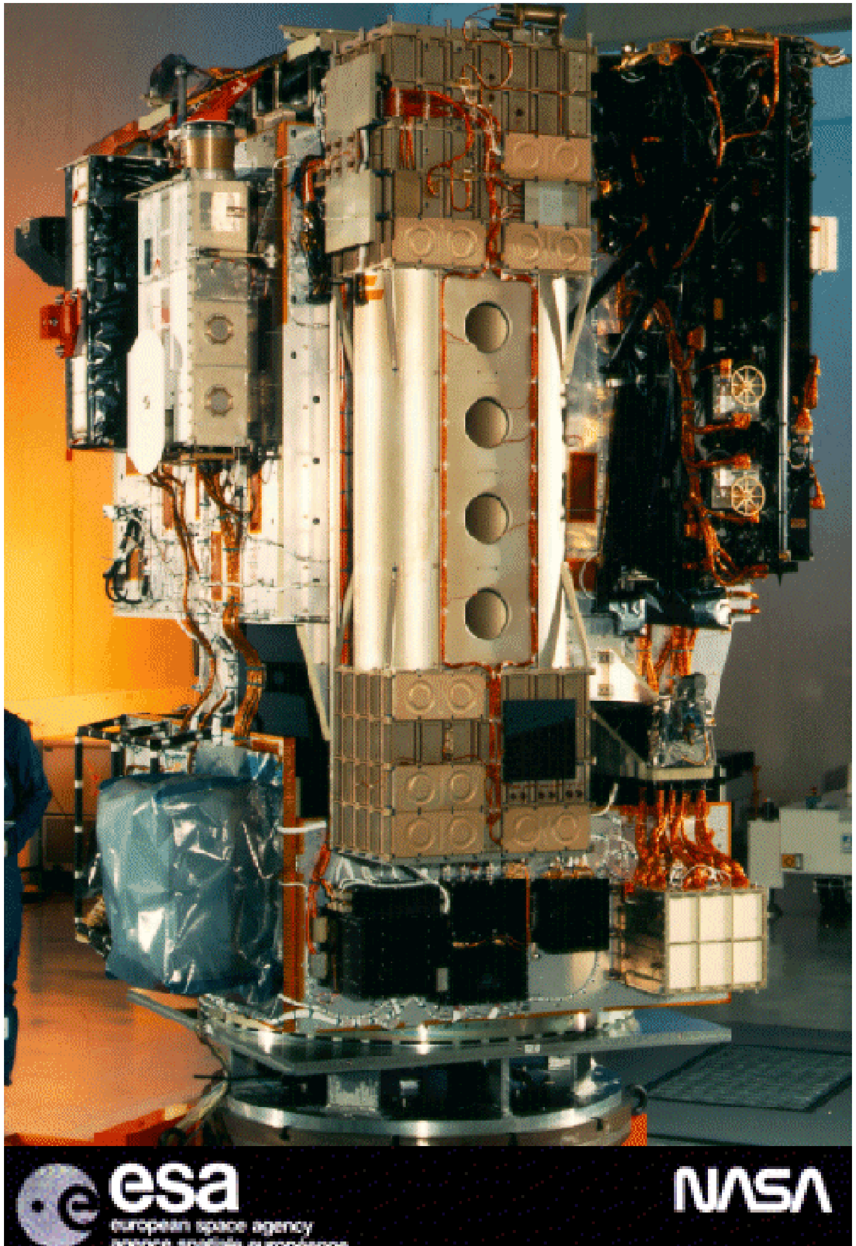

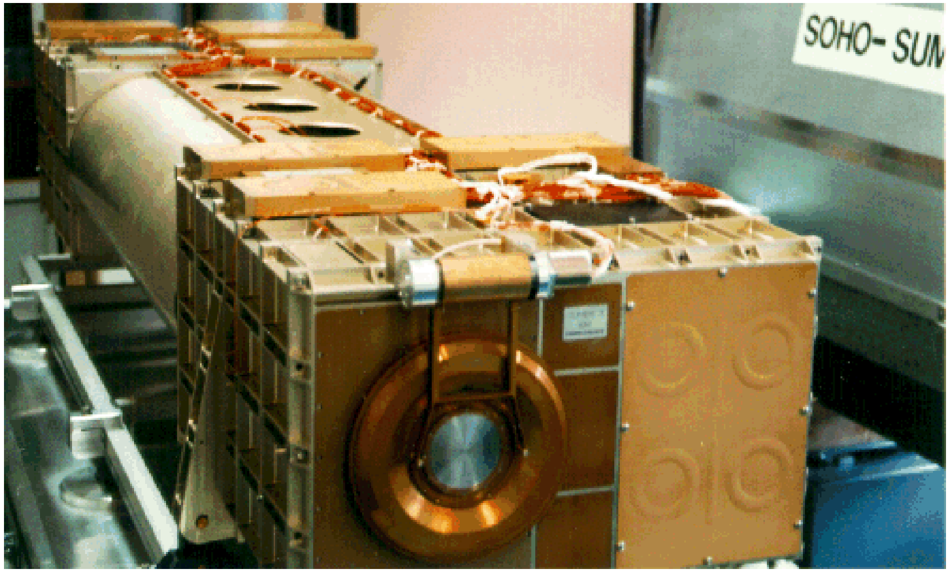

EUV-Spectrograph **SUMER**

Solar Ultraviolet Measurements of Emitted Radiation

spatial resolution: 2” (1” pixel) (1500 km)
spectral resolution: $\lambda/\Delta\lambda \approx$ 30 000
wavelength range: 50 – 155 nm

covering temperatures on the Sun: 5000 – 10^7 K

- dynamics and structure of the transition region from the chromosphere to the corona
- **accuracy for Doppler shifts: ~ 2 km/s**

SUMER: some lines and continua

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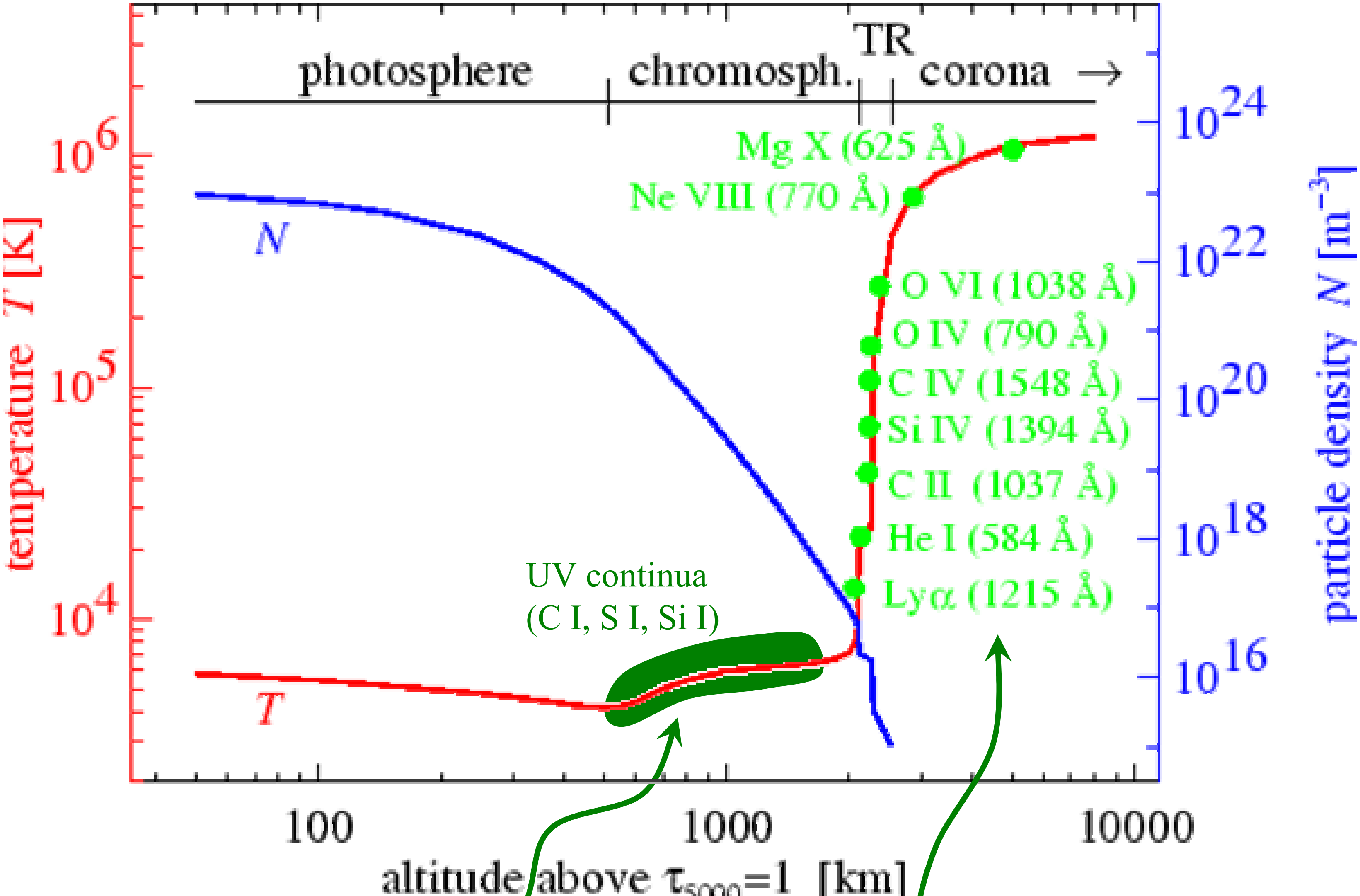

T, *N* following Vernazza et al. (1981) ApJS 45, 635

EUV emission lines from transition region and corona

and neutral lines & **continua** from the chromosphere

SUMER optical design

SUMER slits and image formats

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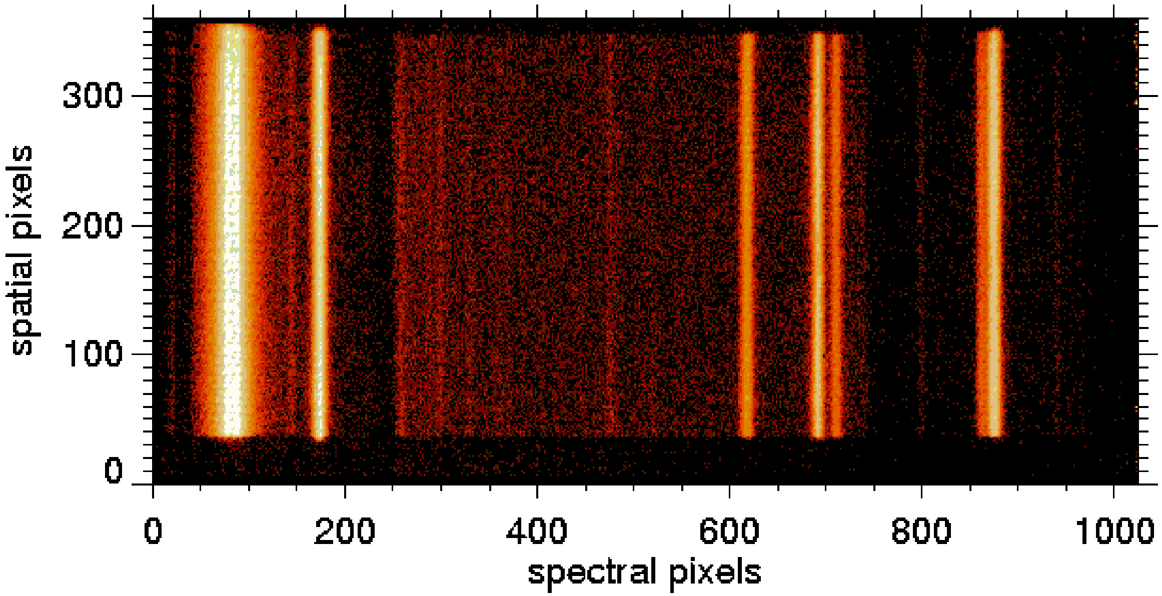


slits available:

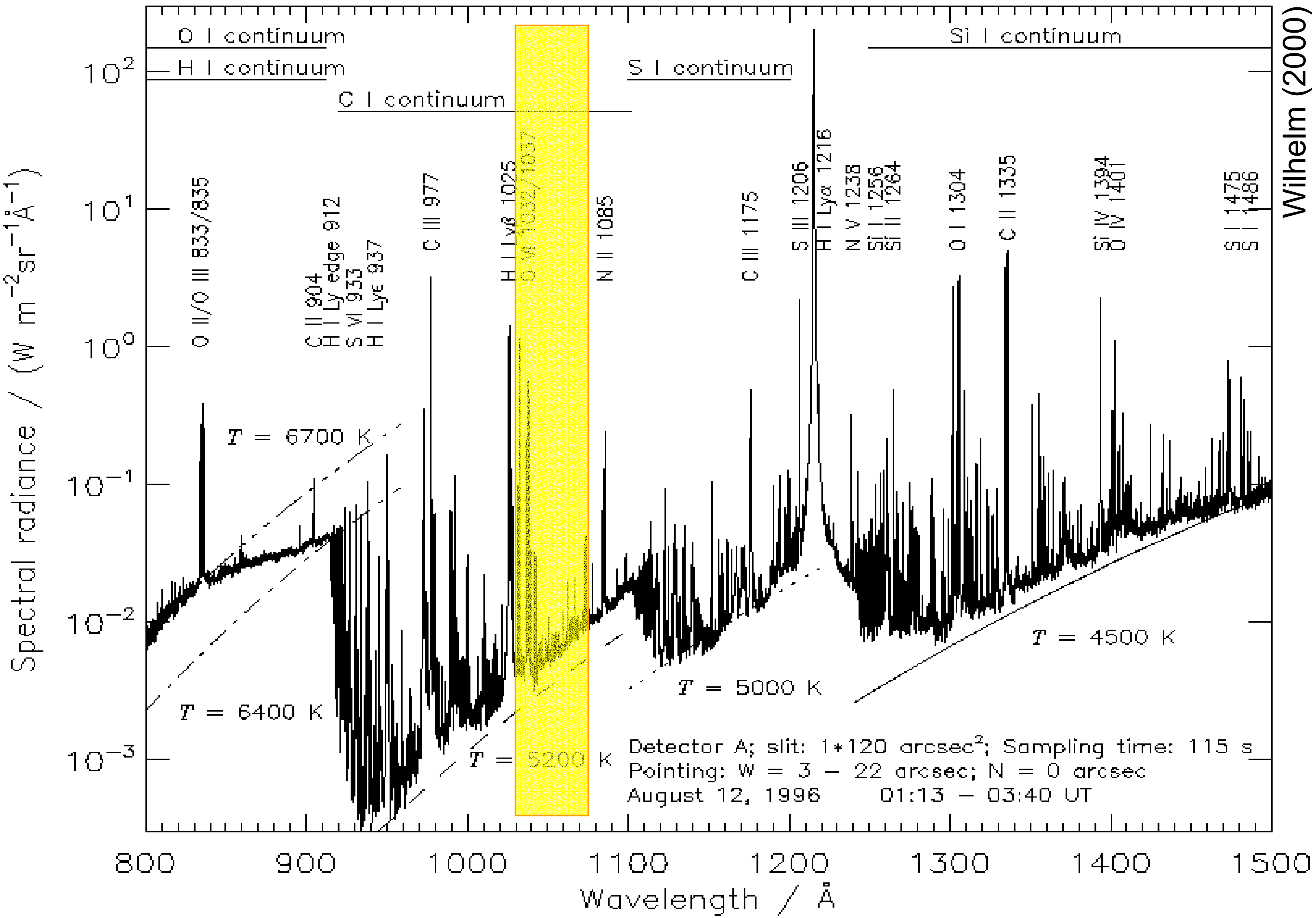
		k =
4''	x 300''	1
1''	x 300''	2
1''	x 120'' : bot/mid/top	3/4/5
0.3''	x 120'' : mid/mid/top	6/7/8

Image formats: (uncompressed)

f =	*spec x spat*	*transmission time for 10 kbit/s*
3:	1024x360	*(590 s)*
5:	1024x120	*(197 s)*
9:	50x360	*(30 s)*
11:	50x120	*(10 s)*
13:	25x360	*(14 s)*
15:	25x120	*(5 s)*
37:	256x360	
39:	512x360	

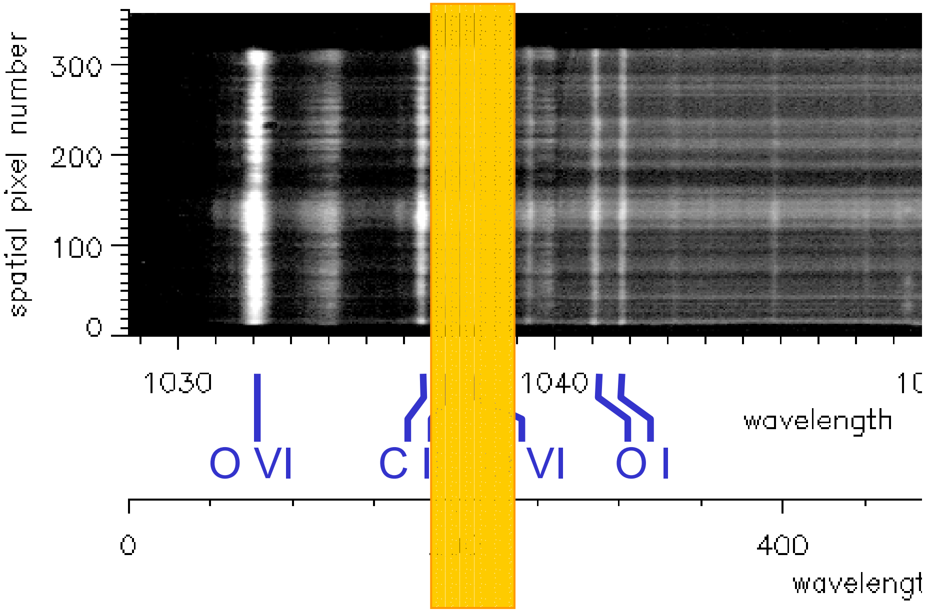
SUMER: spectral range (1st order)

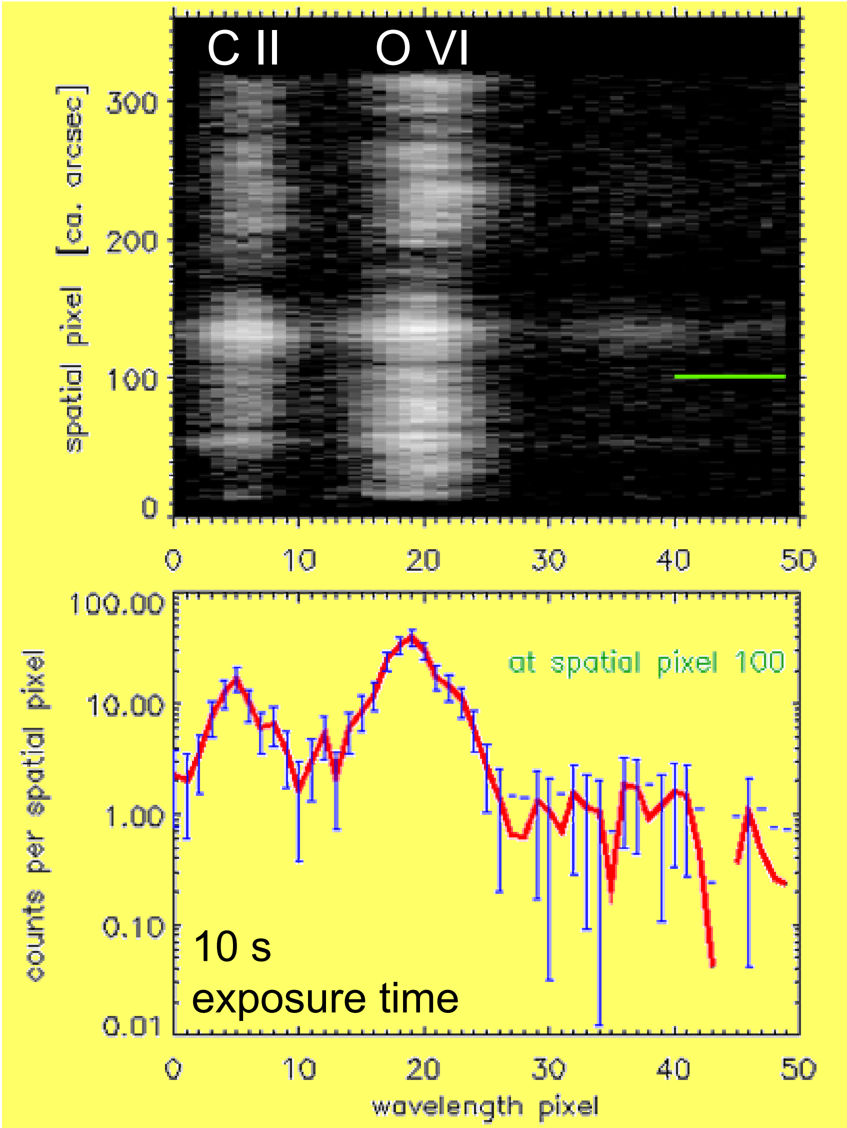
Hardi Peter



Full spectral frame and spectral windows

Hardi Peter





full frame:

1024 spectral pixels ≈ 44 Å (1st order)

spectral window:

often 50 spectr. pxl ≈ 2 Å (1st order)
(or 25, 512, …)

Problem:

sometimes windows not wide enough
(telemetry…)

→ ***Images by raster procedure***

SUMER data formats

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basically two different data formats:

- **FITS / FTS files** available from SOHO data base / MEDOC

  data are automatically grouped:
  one header for a number or images in one fits-file

  PROBLEM: not easy to automatically group complex data...

- **LINDAU-CD-data** available from MPAE in Lindau /Germany
  (http://www.linmpi.mpg.de/english/projekte/sumer/FILE/Download.html)

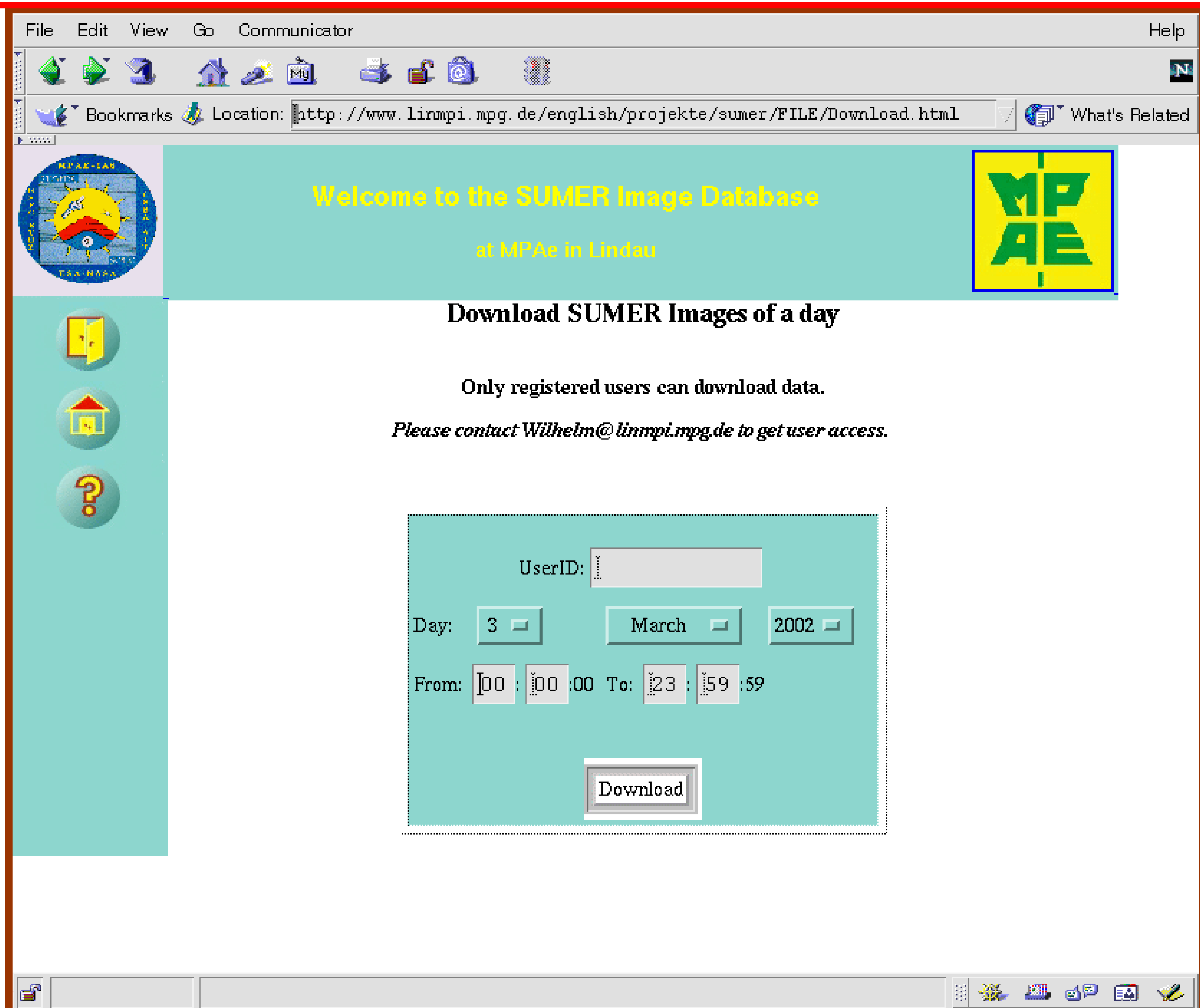
  one (part of) image of the detector - one header

  very simple data structure (but many small files)

  PROBLEM: “very” raw data (e.g. still compressed)

How to get the “Lindau-CD-data”

Hardi Peter



How to get the "Lindau-CD-data"

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Hardi Peter

File Edit View Go Communicator Help

Bookmarks Location: http://www.linmpi.mpg.de/english/projekte/sumer/SUMER/sumivs.cgi?cmd=1 What's Related

The SUMER Image Database

Image list for 22-09-1996

00:00

After

Img	Time	Type	UDP	Cnt	Refpix	Wavel	Slit	ExpTim	SunY	SunZ	Det
161	22-SEP-1996 01:00:22.58	38	1	9	531	1541.50	2	150.00	-451.94	-411.75	A
162	22-SEP-1996 01:02:52.73	38	1	10	531	1541.50	2	150.00	-448.94	-411.75	A
163	22-SEP-1996 01:05:22.88	38	1	11	531	1541.50	2	150.00	-445.94	-411.75	A
164	22-SEP-1996 01:07:53.03	38	1	12	531	1541.50	2	150.00	-442.88	-411.75	A
165	22-SEP-1996 01:10:23.13	38	1	13	531	1541.50	2	150.00	-439.88	-411.75	A
166	22-SEP-1996 01:12:53.28	38	1	14	531	1541.50	2	150.00	-436.88	-411.75	A
167	22-SEP-1996 01:15:23.38	38	1	15	531	1541.50	2	150.00	-433.88	-411.75	A
168	22-SEP-1996 01:17:53.53	38	1	16	531	1541.50	2	150.00	-430.88	-411.75	A
169	22-SEP-1996 01:20:23.68	38	1	17	531	1541.50	2	150.00	-427.88	-411.75	A
170	22-SEP-1996 01:22:53.78	38	1	18	531	1541.50	2	150.00	-424.81	-411.75	A
171	22-SEP-1996 01:25:23.89	38	1	19	531	1541.50	2	150.00	-421.81	-411.75	A
172	22-SEP-1996 01:27:54.04	38	1	20	531	1541.50	2	150.00	-418.81	-411.75	A
173	22-SEP-1996 01:30:24.34	38	1	21	531	1541.50	2	150.00	-415.81	-411.75	A
174	22-SEP-1996 01:32:54.44	38	1	22	531	1541.50	2	150.00	-412.81	-411.75	A
175	22-SEP-1996 01:35:24.89	38	1	23	531	1541.50	2	150.00	-409.81	-411.75	A
176	22-SEP-1996 01:37:55.04	38	1	24	531	1541.50	2	150.00	-406.75	-411.75	A
177	22-SEP-1996 01:40:25.14	38	1	25	531	1541.50	2	150.00	-403.75	-411.75	A
178	22-SEP-1996 01:42:55.44	38	1	26	531	1541.50	2	150.00	-400.75	-411.75	A
179	22-SEP-1996 01:45:25.54	38	1	27	531	1541.50	2	150.00	-397.75	-411.75	A
180	22-SEP-1996 01:47:56.04	38	1	28	531	1541.50	2	150.00	-394.75	-411.75	A

How to get the "Lindau-CD-data"

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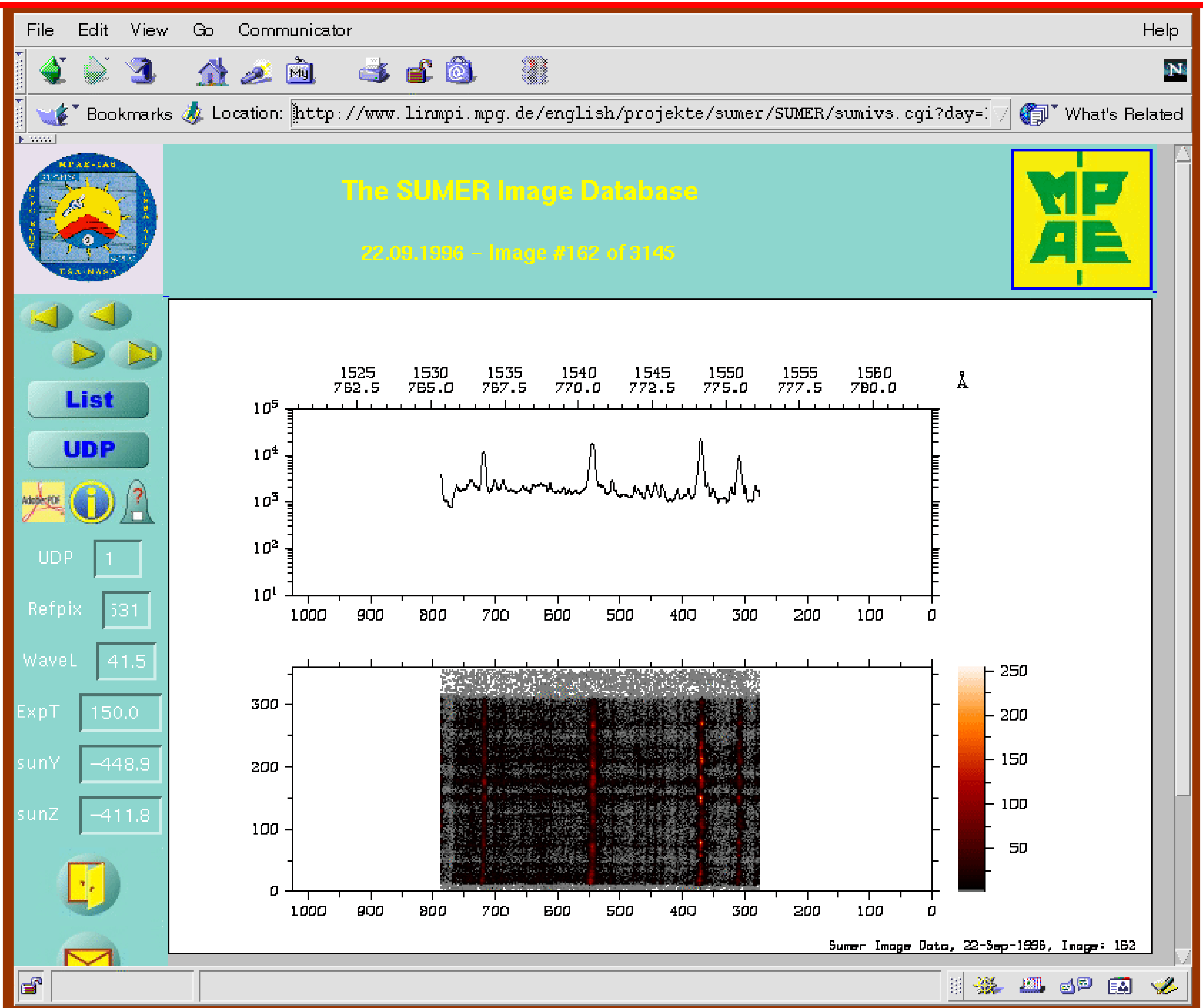

How to get the “Lindau-CD-data”

Hardi Peter

Downloading these data:
a UNIX tar file will be provided for you at an ftp site (e-mail).
This tar file contains the requested images with headers
as IDL save/restore files

SUMER data cookbook:
http://www.linmpi.mpg.de/english/projekte/sumer/text/cookbook.html

The "Lindau-CD-data" files

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Hardi Peter

IDL save/restore files in xdr-format.

- each file contains one single detector image / wavelength window
- along with a 92 element byte array for the header

```
> restore,'sum_r_19960330_00060530.12343_02'

> help, header_data, image_data
HEADER_DATA      BYTE      = Array[100]        (only 92 non-zero elements)
IMAGE_DATA       BYTE      = Array[1024, 360]  (spectral x spatial)

wavel(header_data)            ->  1234.35
pixpos(header_data)           ->  511
utc_head(header_data,/ecs)    ->  1996/03/30 00:06:05.302
exptim(header_data)           ->  300
imgform(header_data)          ->  2
comprm(header_data)           ->  5
slitnum(header_data)          ->  1
imgtot(header_data)           ->  1140904807
suny(header_data)             ->  -1100.06
sunz(header_data)             ->  -0.375000
detector(header_data)         ->  1
rotcomp(header_data)          ->  0.00000
popudp(header_data)           ->  1
```

header functions provided in SSW

A sample data strategy

KIS Hardi Peter

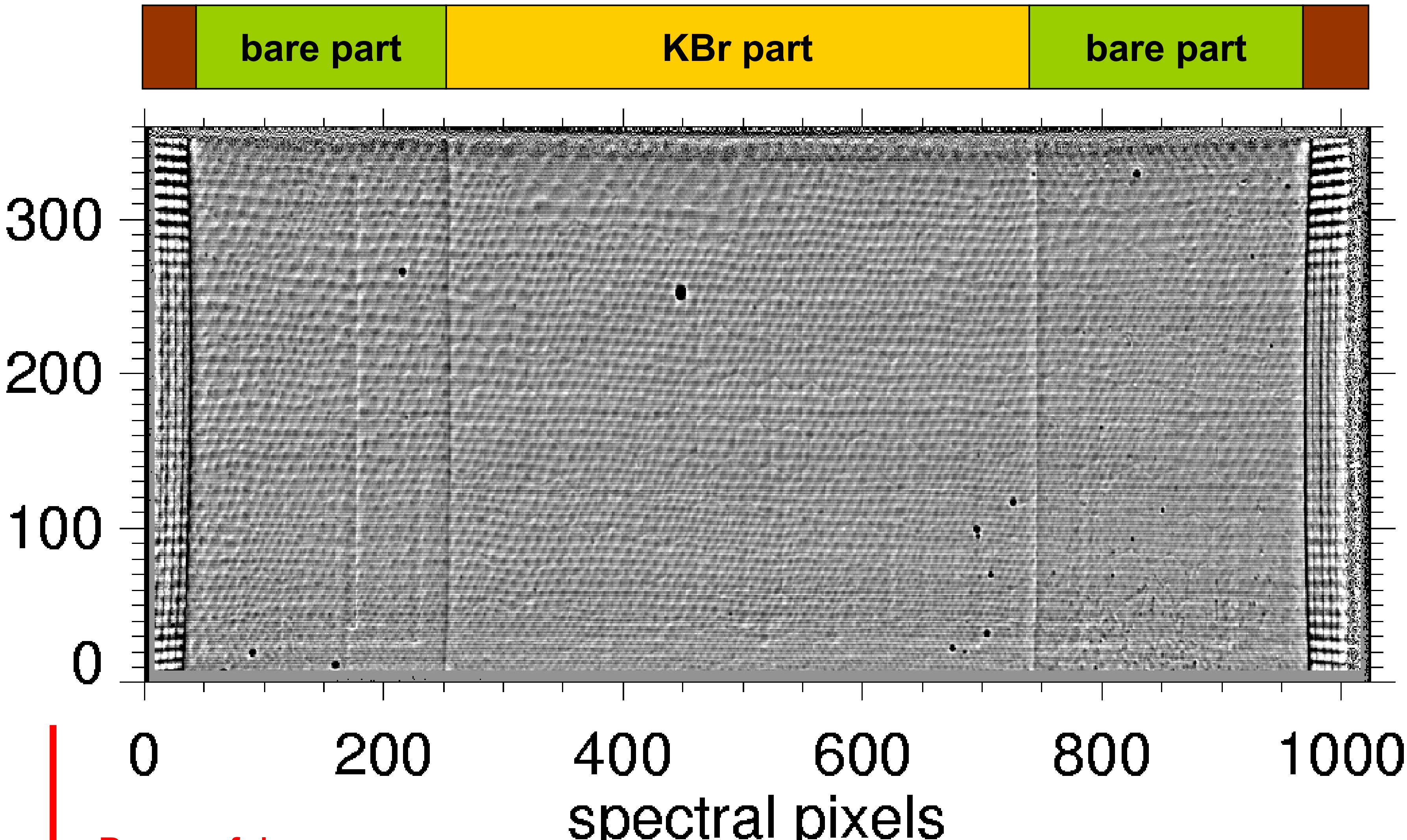
group data (either from FITS-files or CD-data) into items consisting of:

```
d [ nwave, nspat, nline, ntime, nraster ]

nwave:      # spectral points
nspat:      # spatial points
nline:      # spectral windows
ntime:      # time steps
nraster:    # raster steps

date_obs:   start time
del_time:   time steps
exp:        exposure time

ref_px:     spectral ref-pixel
wave:       wavelength at ref_px
disp:       spectral dispersion

ref_py:     spatial ref-pixel
spat:       spatial disersion
solar_x:    solar X
solar_y:    solar Y at pef_py
```

- use **sumer_cat(_cd).pro** and supply **sumer_item(_cd).pro** to construct items.
- each of these data sets stored in one "item file", e.g. "**itemr_0_19960922.idlsave**"
- then use
  sumer_ff, date, item
  sumer_geo, date, item
  for flatfield & geo.distorsion correction
- fits-files: Carlson, Judge, Hansteen (http://folk.uio.no/matsc/sumer/index.html)
- Lindau (_cd) data: H. Peter (peter@kis.uni-freiburg.de)

SUMER detector and flatfield image

Hardi Peter



Be careful:
in “original” CD-data

NORTH

Wavelength

SUMER on-board data compression

Hardi Peter

- reduce telemetry by reducing digitalisation from 16 to 8 bit (compression wid data loss)

  Mostly used:

  m=5: quasilog (min,max) logarithmic scaling; no loss if max-min count < 256

  1s for 50x360 *(telemetry: 30s → 15s)*

  20s for 1024x360 *(telemetry: 590s → 295s)*

- calculate moments of line profiles: (~1 s on-board)

  for a Gaussian

  $$\phi = I_m \exp\left(-\frac{(v - v_0)^2}{w^2} \right)$$

  these are:

$$\begin{cases} I_{tot} = \int \phi \, \mathrm{d}v \\ v_0 = \dfrac{\int \phi \, v \, \mathrm{d}v}{I_{tot}} \\ w^2 = \dfrac{2 \int \phi \, (v - v_0)^2 \, \mathrm{d}v}{I_{tot}} \end{cases}$$

$$I_m = \frac{I_{tot}}{\sqrt{\pi} \; w}$$

only these moments are transmitted down
- either moments for one Gaussian in a window (***m***=7...12)
- or 5 moments of 3 lines (***m***=17)

be careful: continuum / line outside window / signal-to-noise / non-Gaussians

Dead time correction

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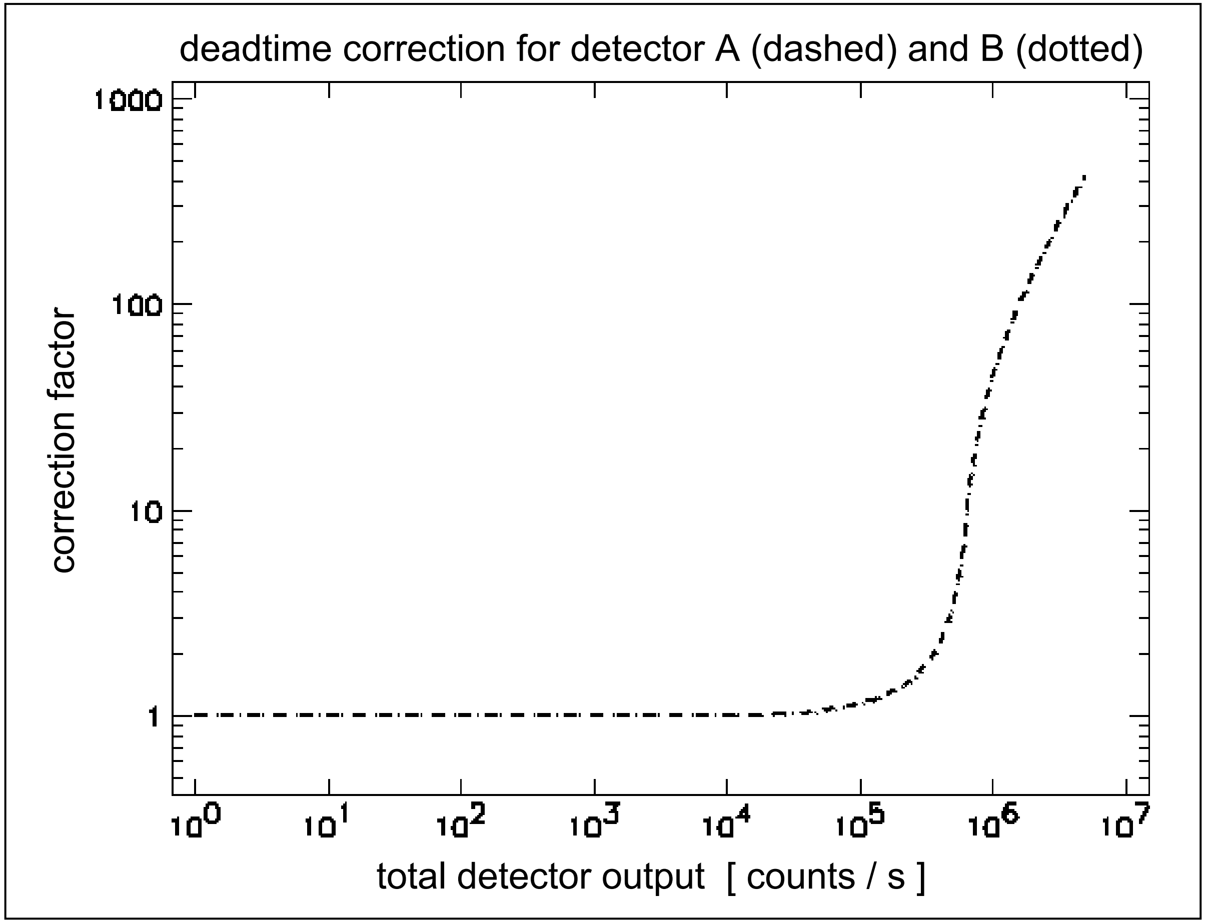
use **deadtime_corr. pro** (part of SSW)

➢ **deadtime_corr, detector, original, corrected**

`detector='A' or 'B'`

to be applied before local gain depression correction

deadtime effects become significant for total count rates of 50000 counts/s and more (conservative)



Gain correction

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corrects for Local Gain Depression

use **local_gain_corr.pro**
(part of SSW)

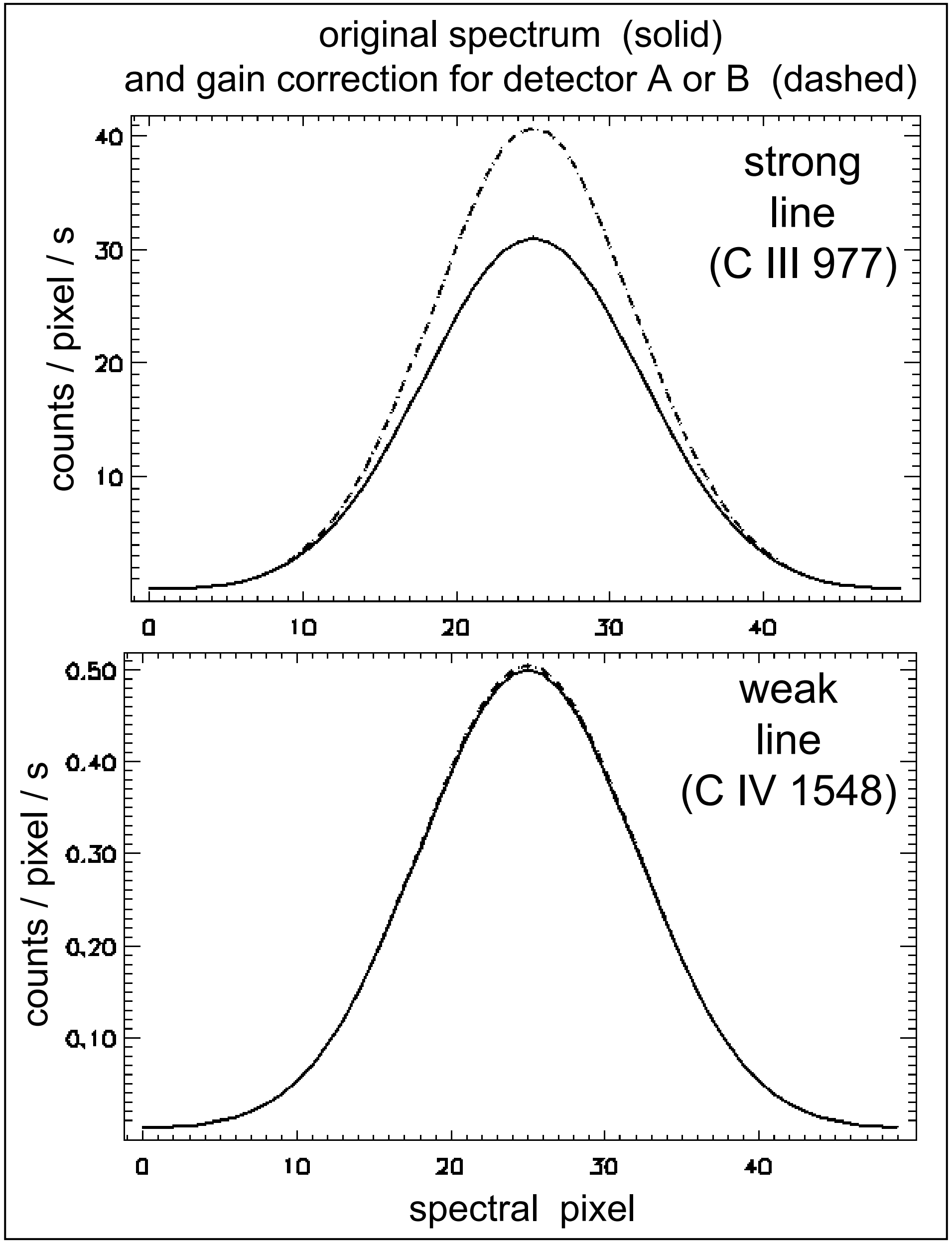
```
local_gain_corr, detector $
               , original $
               , corrected
```

```
detector='A' or 'B'
```

```
original and corrected in
counts/pixel/s
```

apply deadtime correction first

important already for
relatively weak lines



Flatfield Correction

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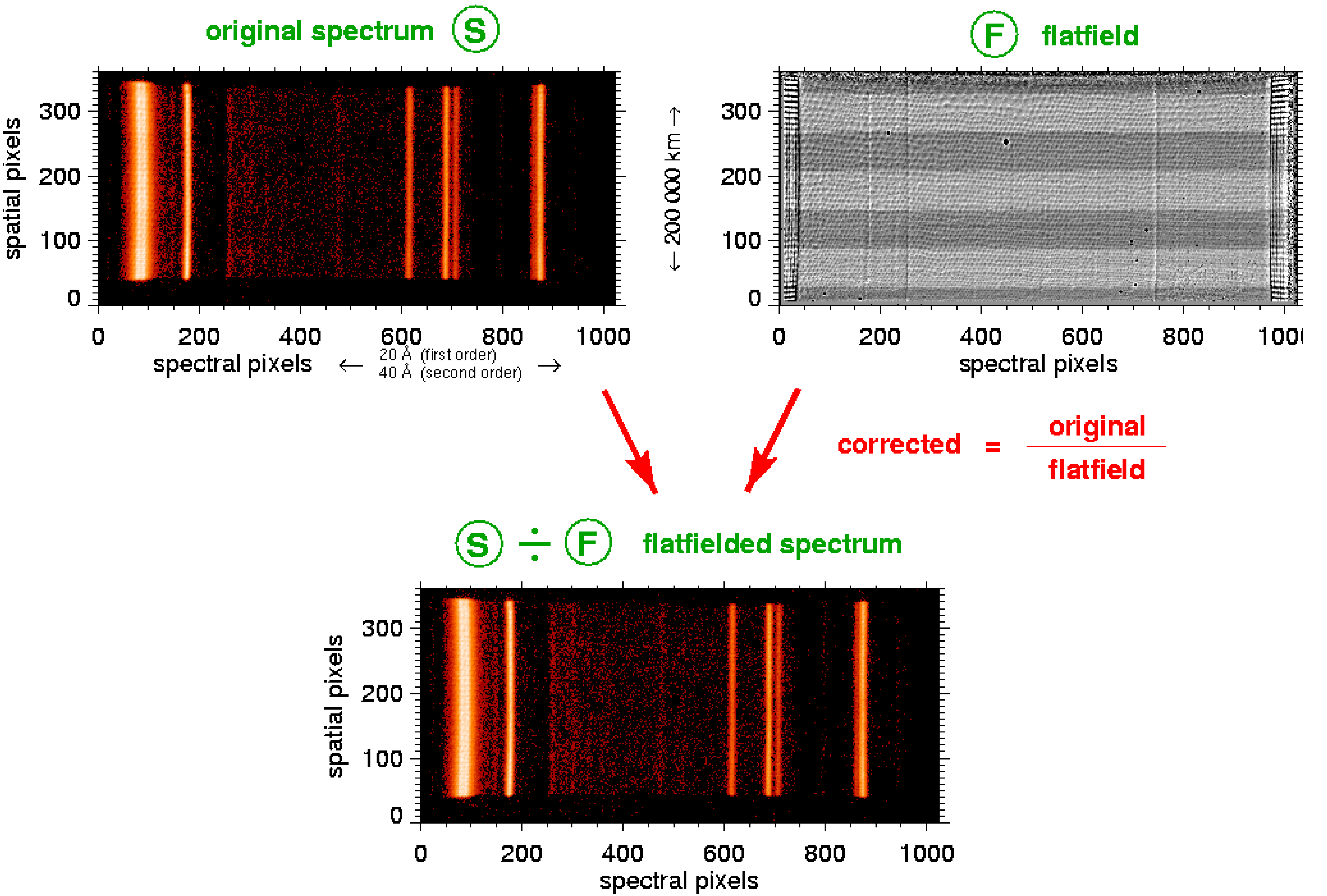
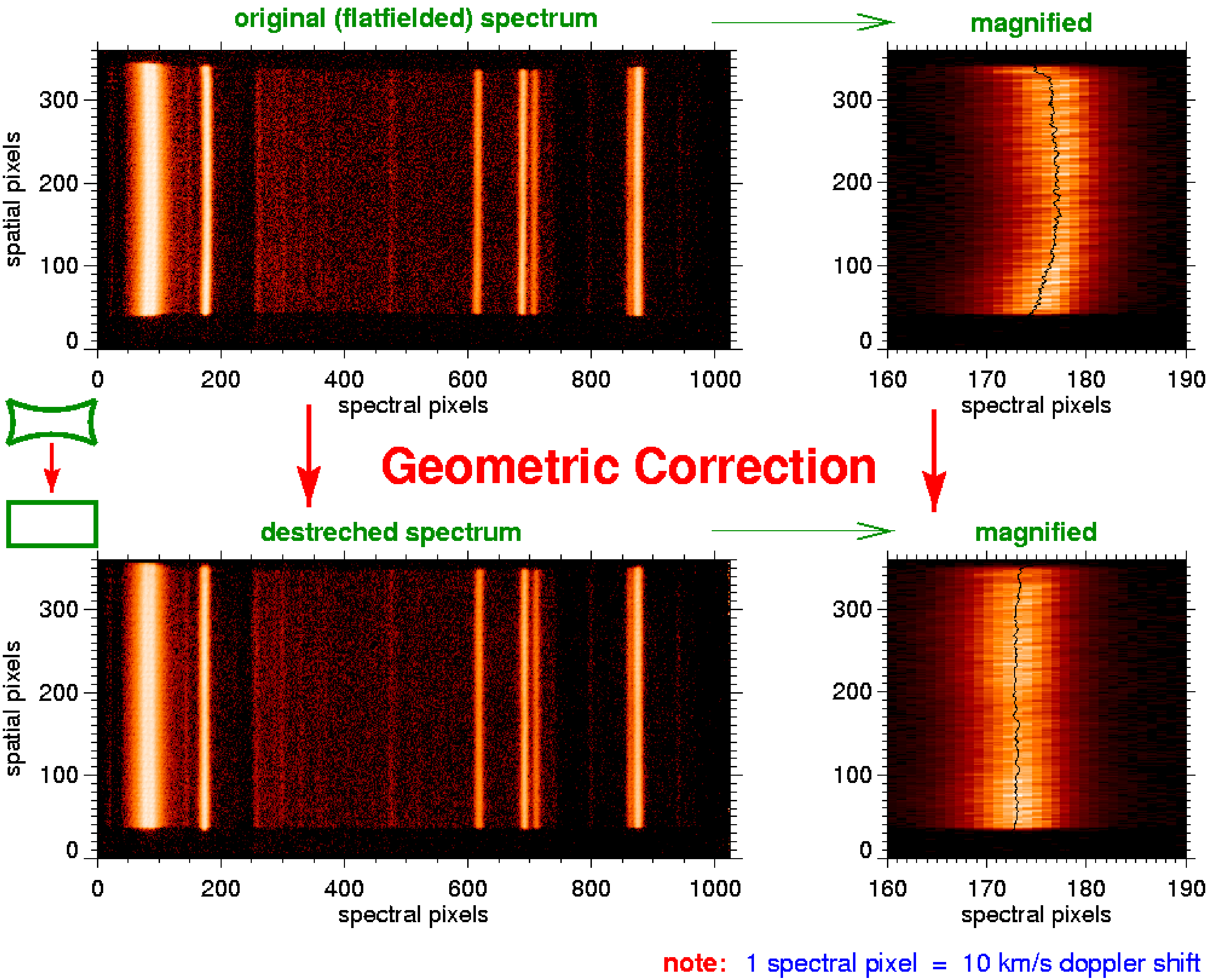
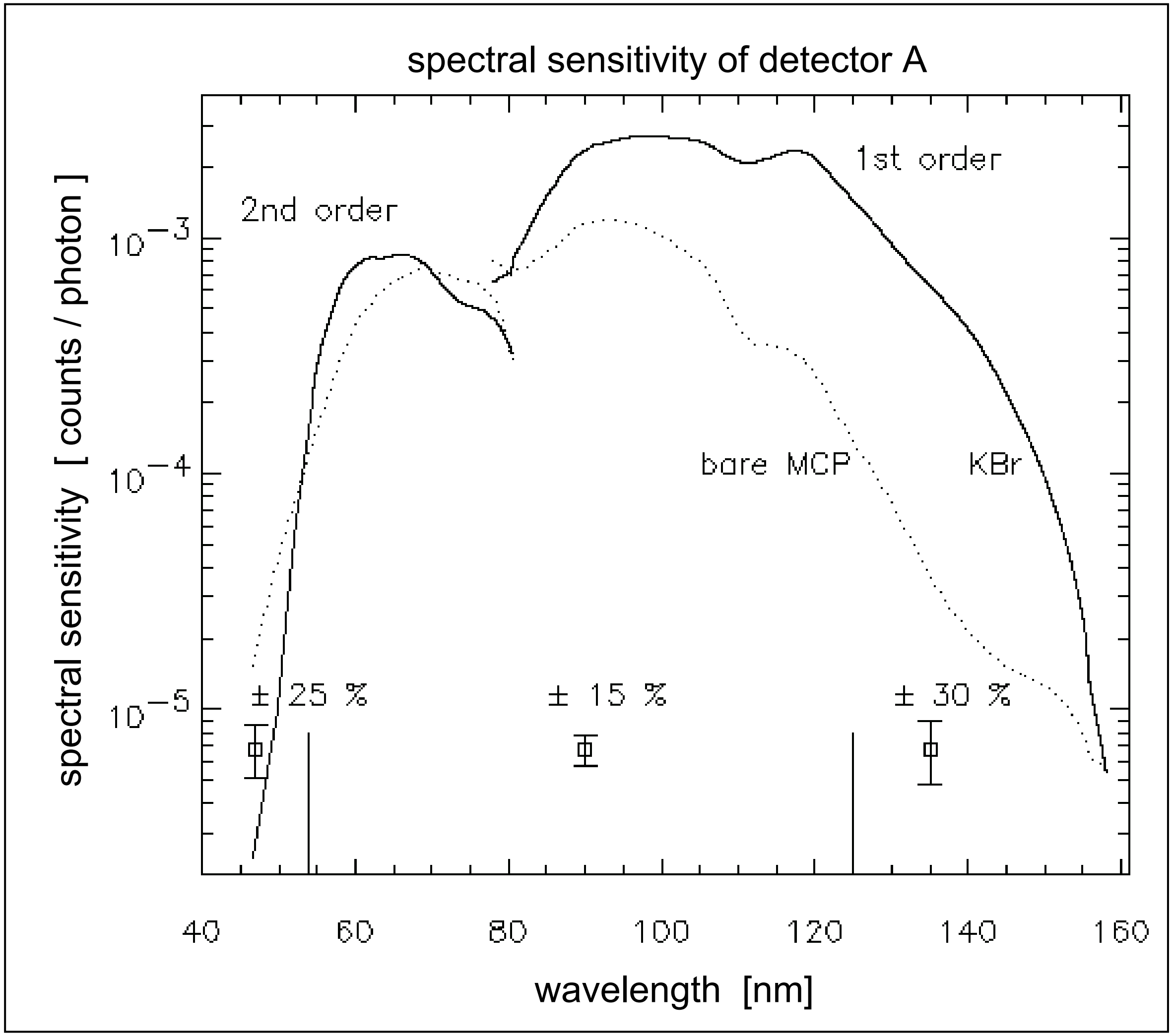



original (flatfielded) spectrum
magnified
spatial pixels
spectral pixels
Geometric Correction
destreched spectrum
magnified
spatial pixels
spectral pixels
note: 1 spectral pixel = 10 km/s doppler shift

Radiometric calibration

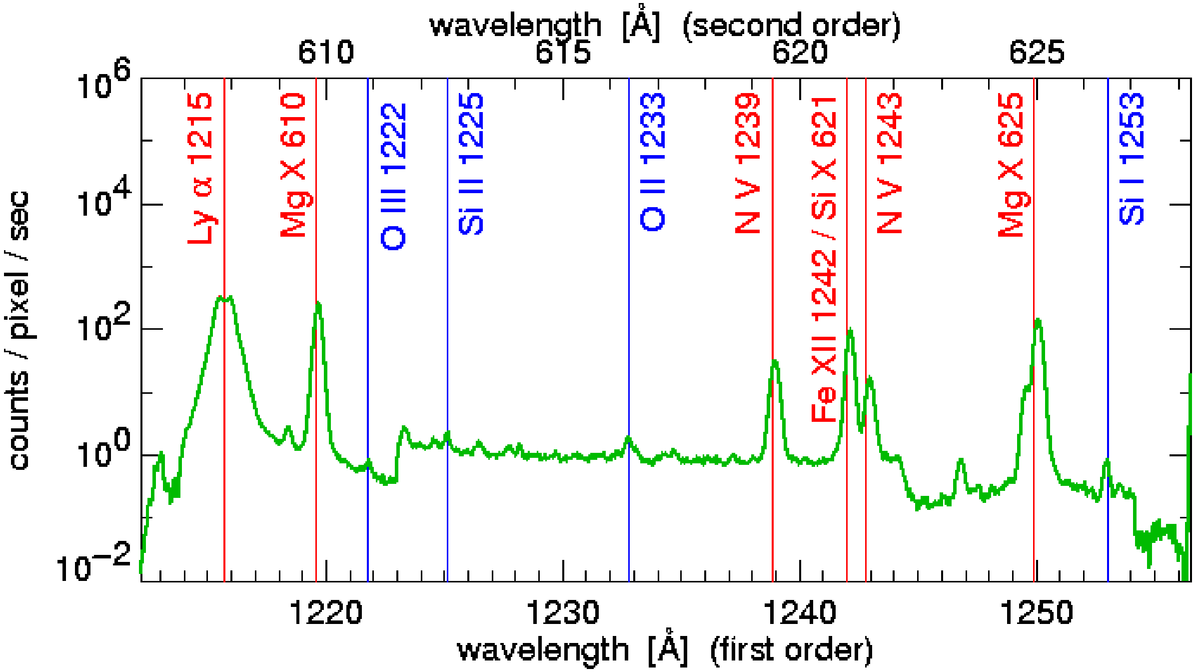
use **radiometry.pro**
(part of SSW)

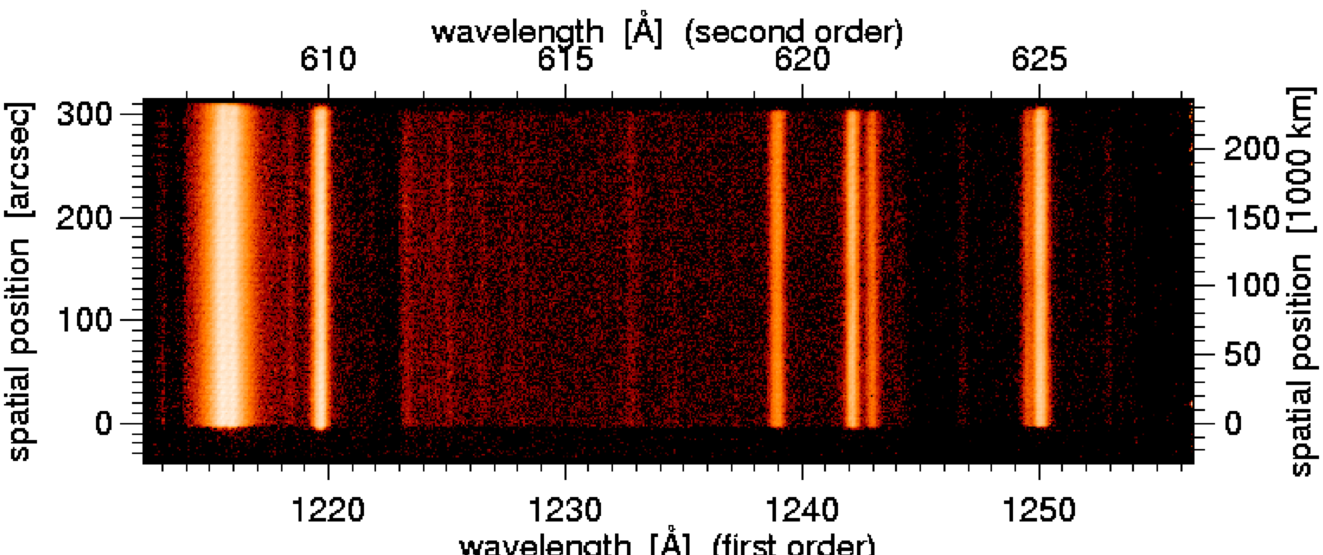
```
r=radiometry( $
   slit $
 , wavelength $
 , order $
 , count_rate $
 , Bare=Bare $
 , px=px $
 , line=line $
 , sun_line=sun_line $
 , arcsec=arcsec $
 , photons=photons $
 , Watts=Watts $
 , Det_B=Det_B
```



The difference in sensitivity of KBr and bare parts allow for deconvolution of 1st and 2nd order

Wavelength calibration

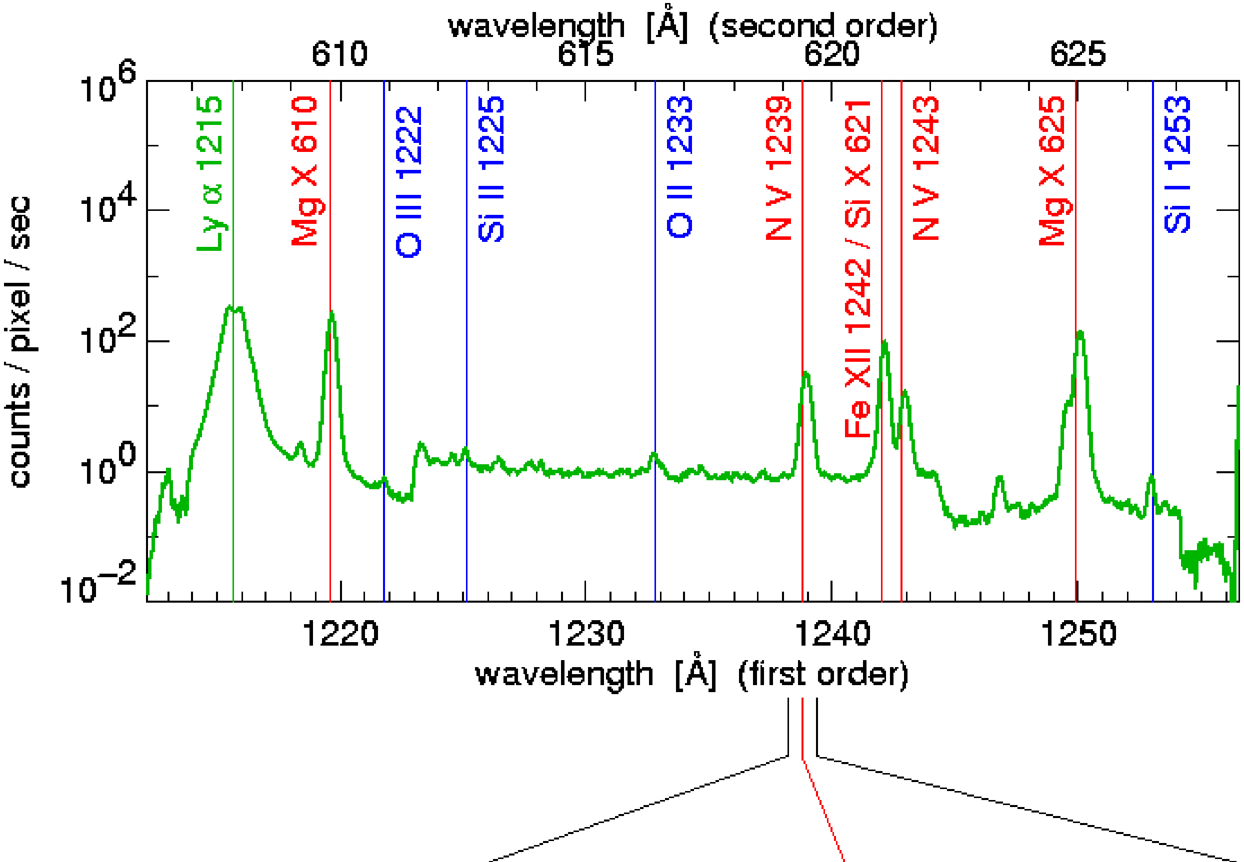




- SUMER has *no* on-bord calibration lamp
- use “cool” lines that show little or no systematic shifts for calibration

  best: chromospheric lines

Absolute Doppler shifts



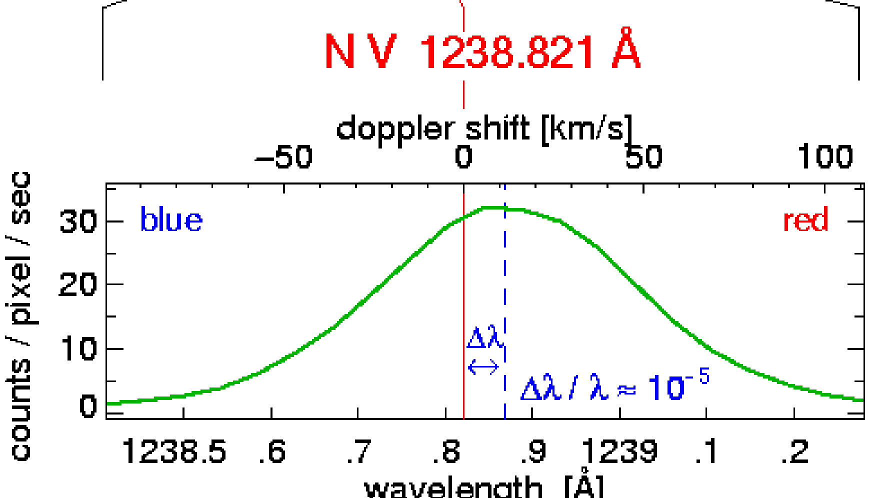
LINE SHIFT:

$$\lambda = 1238.821 \text{ Å}$$
$$\Delta\lambda = +0.047 \text{ Å}$$

$$v_D = \frac{\Delta\lambda}{\lambda}\, c$$

= +11.3 km/s

→ red-shifted



- use wavelength calibration
- determine "solar" wavelength (moments, Gaussian fit, ...)
- compare to rest wavelength (e.g. from laboratory)
- calculate line shift
- *Problem:* often rest wavelengths are poorly known, especially for highly ionised species

Doppler shifts: what do / can we expect ?

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Hardi Peter

observed particle flux at Earth: $\Phi_{1AU} = 2 \cdot 10^{12} \frac{1}{m^2\,s}$

particle / mass conservation:

$\Phi_{TR} = 5^2 \times 7 \times 214^2 \times \Phi_{1AU}$

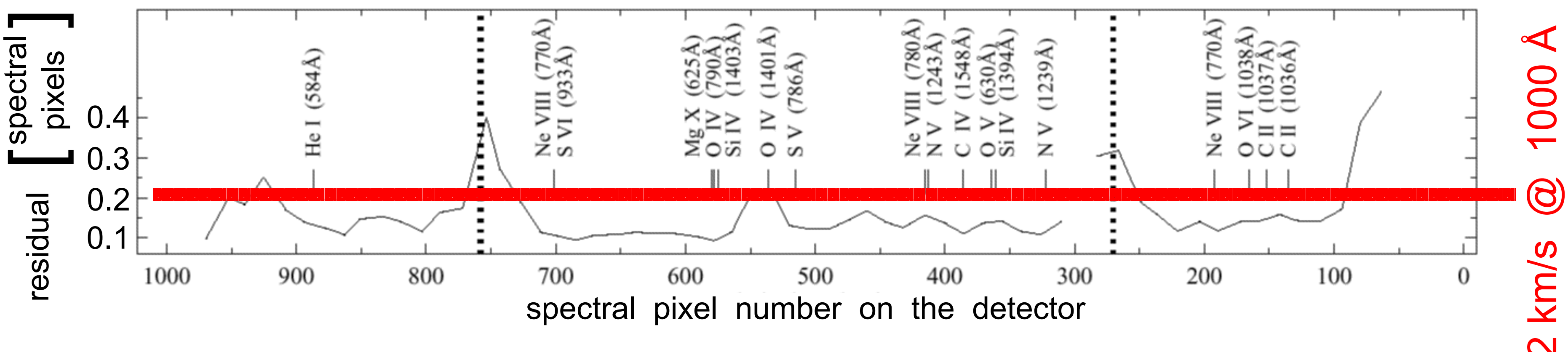
- 5^2: network funnels
- 7: super-radial expansion
- 214^2: radial expansion

velocity to be expected in TR (10^5 K):

$$v_{TR} = \frac{\Phi_{TR}}{n_{TR}} = 3\ \text{km/s}$$

(VAL: $5 \cdot 10^{15}\ m^{-3}$ at 10^5 K)

"accuracy" of SUMER: ca. **2 km/s** (@ 1000 Å: 1 pxl ≈ 10 km/s)



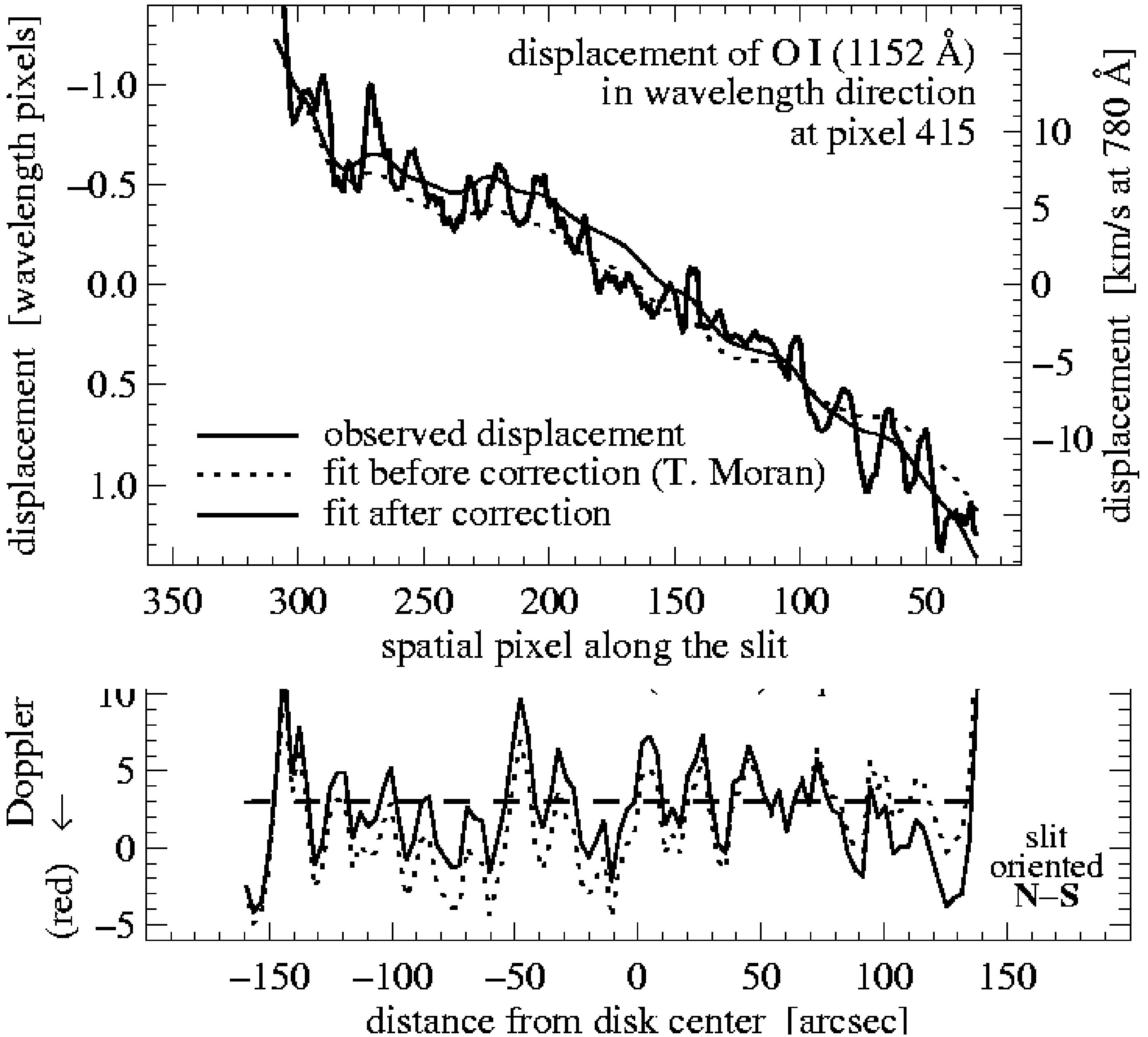
Peter & Judge (1999) ApJ 522, 1148

Correction of geometric distorsion: large scales

Hardi Peter

- T. Moran placed O I (1152) at 60 different positions on the detector
- residuals for line shifts at 60 spectral pixels
- spline fit (dashed) at all pixels
- interpolate in spectral direction

Problem: distorsion pattern changes!



Small scale geometric distortion

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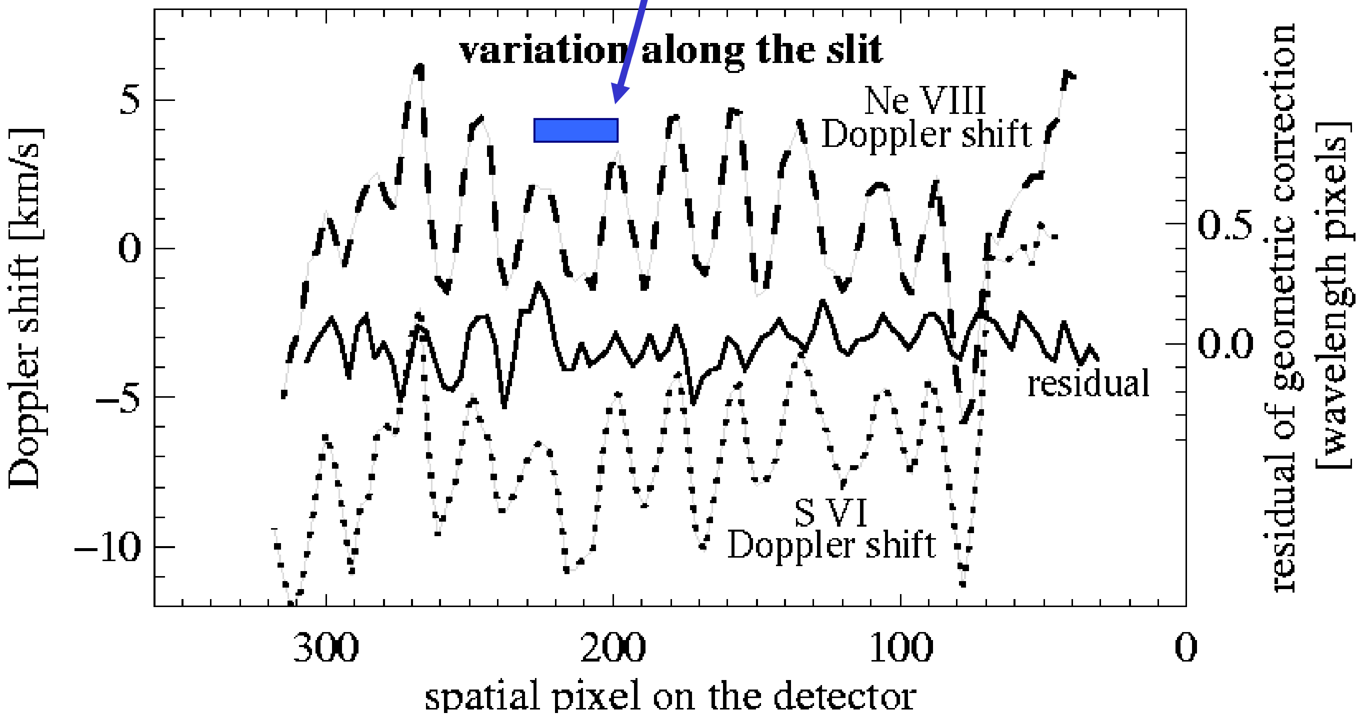
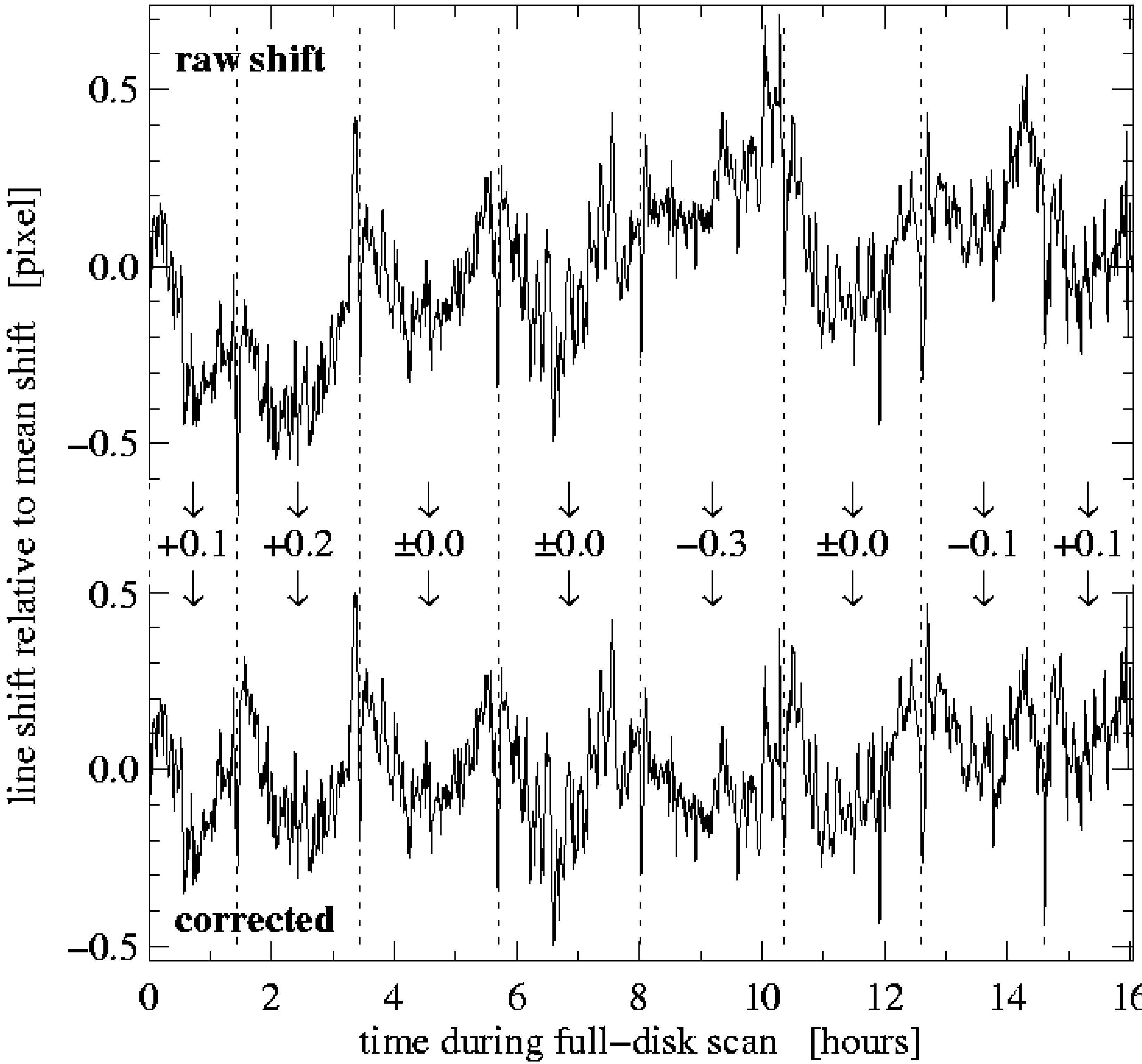
Hardi Peter

- spatial variation of line shift signal of up to 0.5 or more spectral pixels !!
  this corresponds to 5 km/s peak-to-peak
- typical scale corresponds to about 25,000 km on the Sun
  this is comparable to the super-granular scale!
- never trust cell-network analysis based on "single slit observations" !!!
  they might simply reflect the detector patterns.



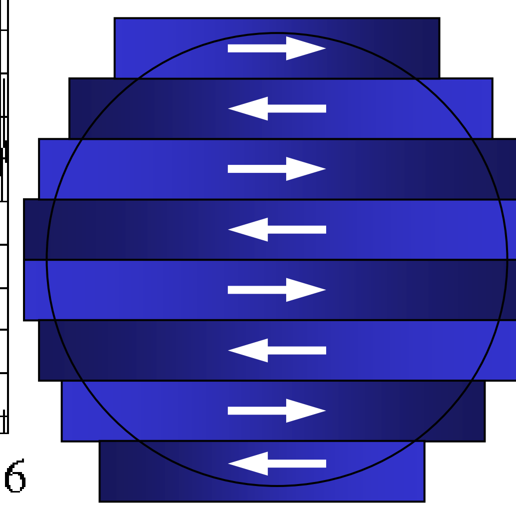
Thermal drift



- line shifts "oscillate" with a period of about 2 hours due to thermal changes

  (time scale of heat control; all mechanisms heat...)

(full disk scans Peter 1999 ApJ)



Some surprises...

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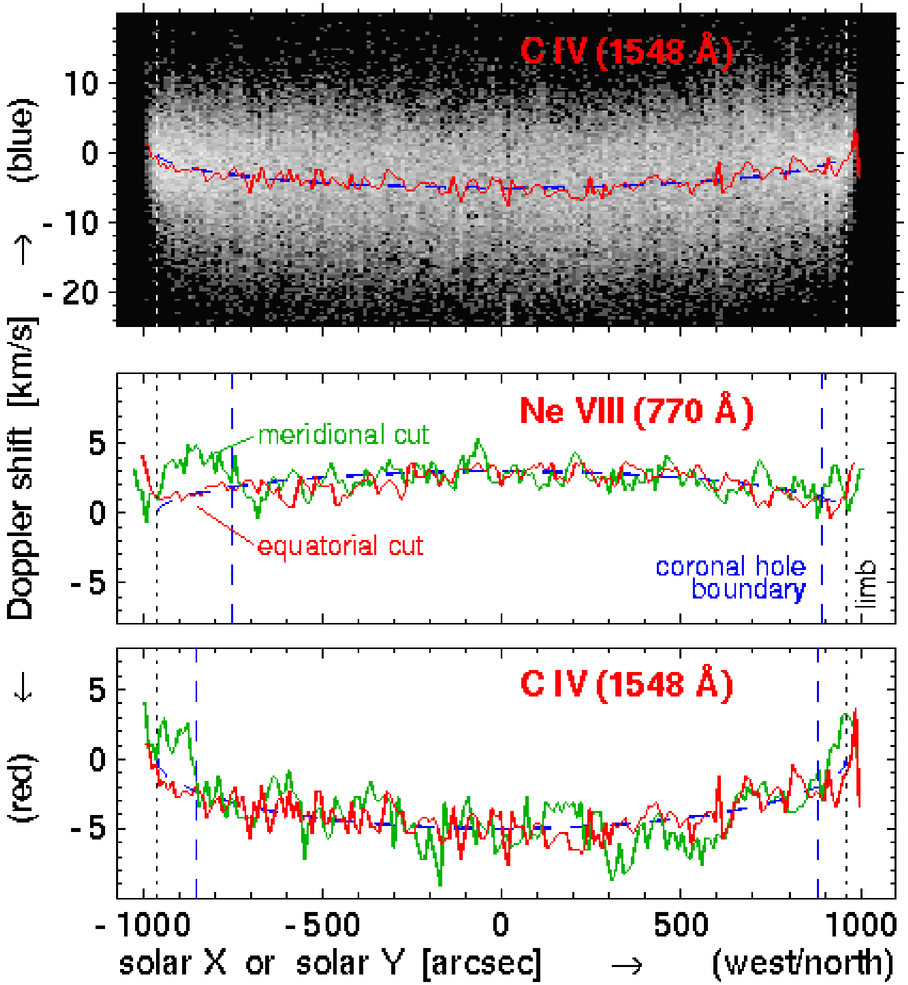
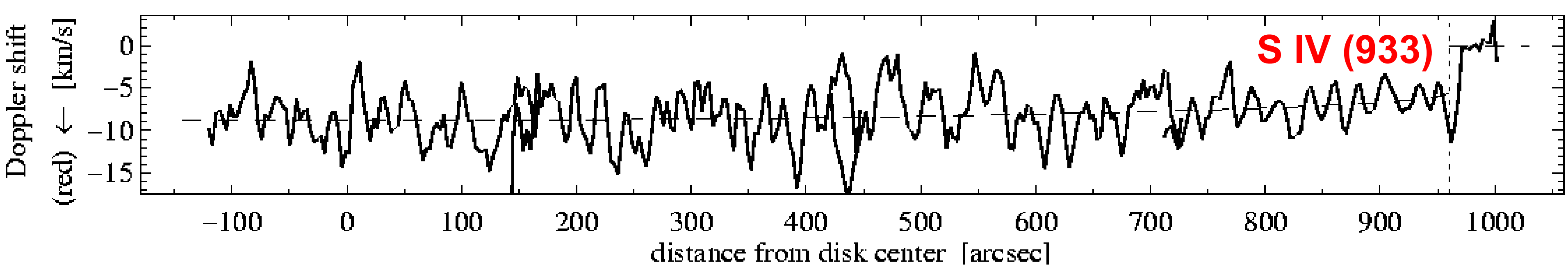


also absorption lines
in one wing of the line of interest
can influence Doppler shift

Here: Ni I line in blue wing
of S IV line
towards the limb
chromosphere might intersect
line-of-sight for TR line



Issues for Doppler shift calculations

- **Instrumental:**
  - >> geometric distorsion — limits to about 1-2 km/s; problematic if no large raster available
  - >> thermal drifts — correct for 2 km/s systematic variation; problem for raster scans: time/space

- **determination of line position**
  - >> moments of line profile — problem:signal-to-noise, line outside window
  - >> proper Gaussian fit — always use Gaussian fit !!! (Genetic Algorithm of MPcurvefit) accuracy ~0.1 pixel, about 1 km/s

- **other issues:**
  - >> emission line blends — Multi-Gaussian fit
  - >> absorption line blends — ??? better hope there are none...

- **estimation of continuum** — be careful especially for moment calculation; very important for line width; problem: often narrow windows

Instrumental width

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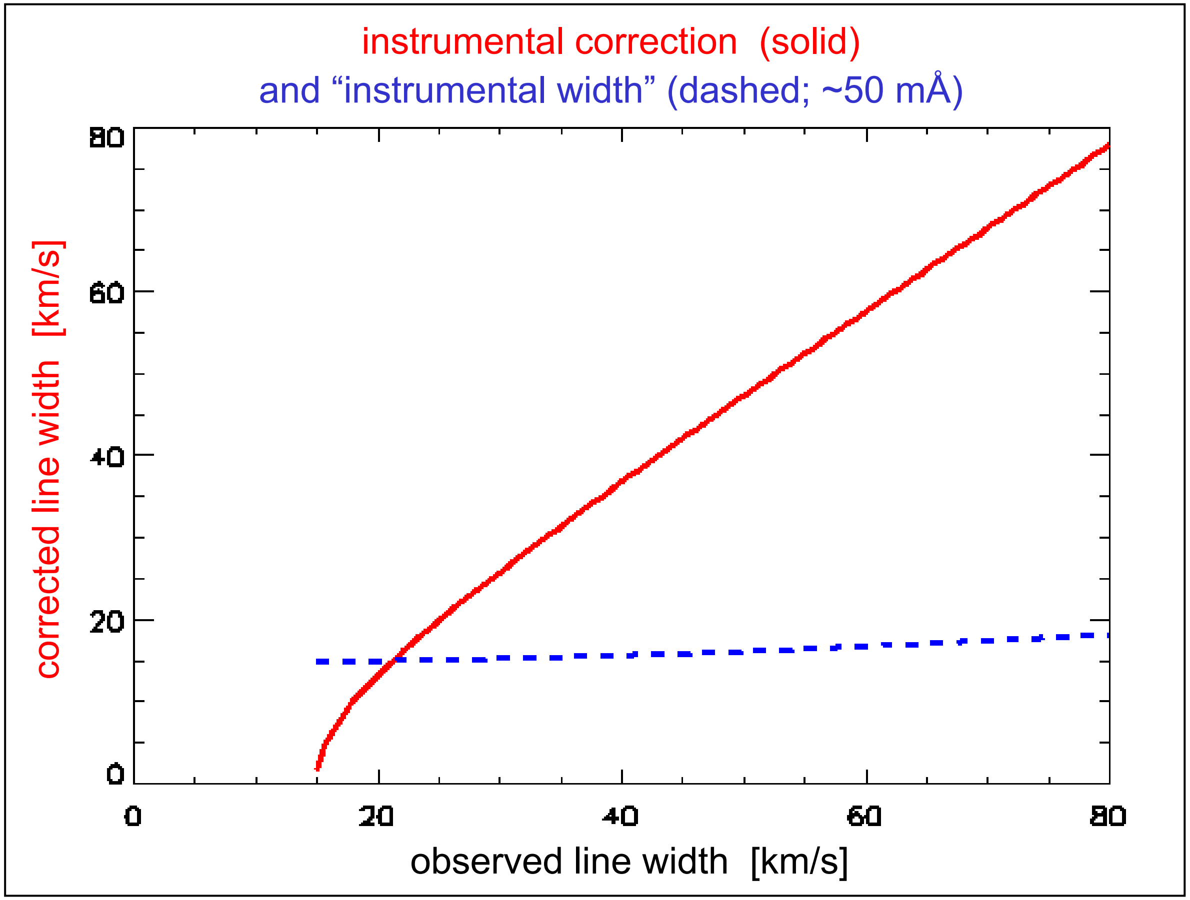
to correct for instrumental width use `con_width_funct_2.pro` (in SSW)

```
>corr = con_width_funct_2( $
        , slit $
        , wavelength $
        , order $
        , fwhm_observed $
       [, /FWHM ] $
       [, /detB ] )
```




```
slit=1: 4x300
     2: 1x300
     3: 1x120 bottom
     4: 1x120 middle
     5: 1x120 top
     6: 0.3x120 bottom
     7: 0.3x120 middle
     8: 0.3x120 top

wavelength: in Ångstrom
order: spectral order (1 or 2)
fwhm_observed: FWHM in mÅ

/FWHM: return width as FWHM,
      default is Gaussian 1/e width
/detB: for detector B
```

Conclusions

- **SUMER wavelength range is unique:**

  short and longward of Lyman continuum (911 Å) from ~500 to ~1600 Å

  >> contains EUV continua from chromosphere (>911 Å)

  >> contains numerous lines from upper chromosphere (neutrals)
  transition region and low corona (<10^6 K)

  >> contains "flare" lines (>10^7 K)

  only instrument to span this large range of physical regimes!

- SUMER has moderate radiometric accuracy (30%)
- very good spectral resolution to study line shifts (2 km/s) in quiet Sun
- small instrumental braodening (50 mÅ ~ 15 km/s)
  of the order or smaller than thermal and non-thermal line widths

- Complex data formats and data analysis