An introduction to SPEX

E. Costantini

J. Kaastra, J. de Plaa

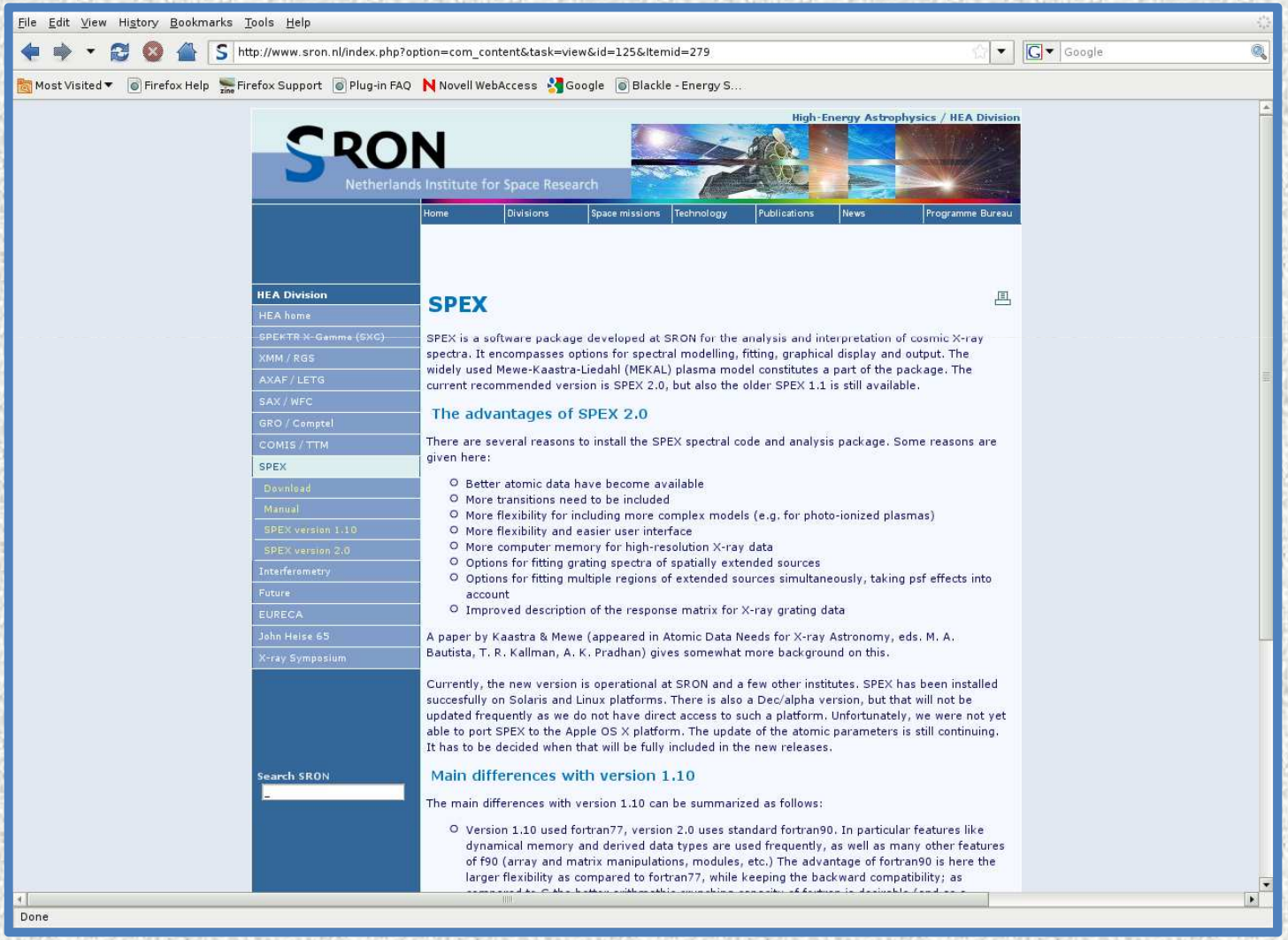
SRON

Introducing SPEX

- SPEX is a fitting package for X-ray spectral analysis
- Similar packages: XSPEC *(Arnaud et al. 1996)*, ION *(Netzer et al. 2002),* PHASE *(Krongold et al. 2003)* ISIS *(Houck & Denicola 2000)*
- SPEX is optimized for high-resolution spectroscopy:
  - Most updated atomic data bases
  - Several multi-parameters absorption/emission models → accurate analysis of narrow features produced by different astrophysical processes

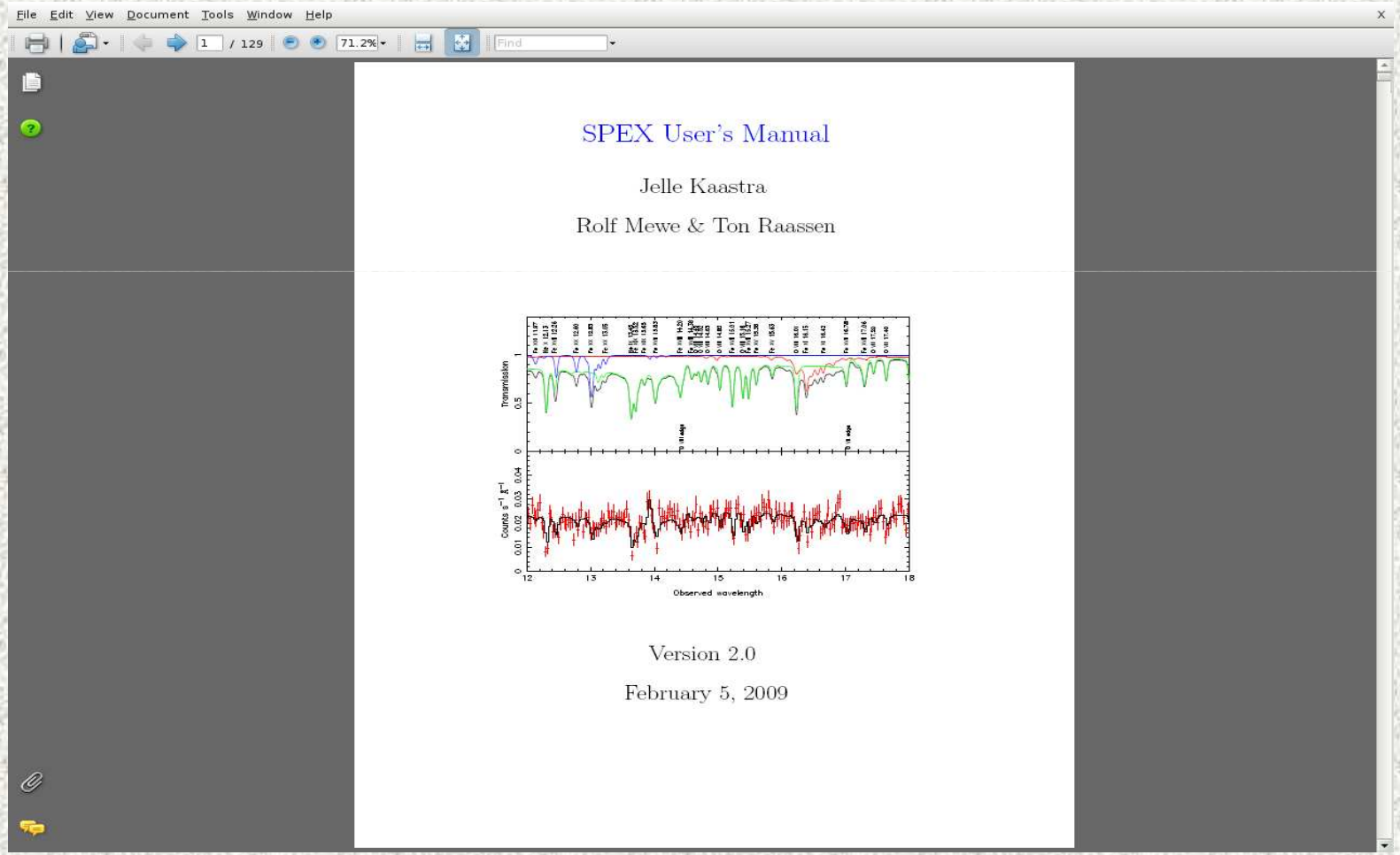
Where to get SPEX

www.sron.nl/spex



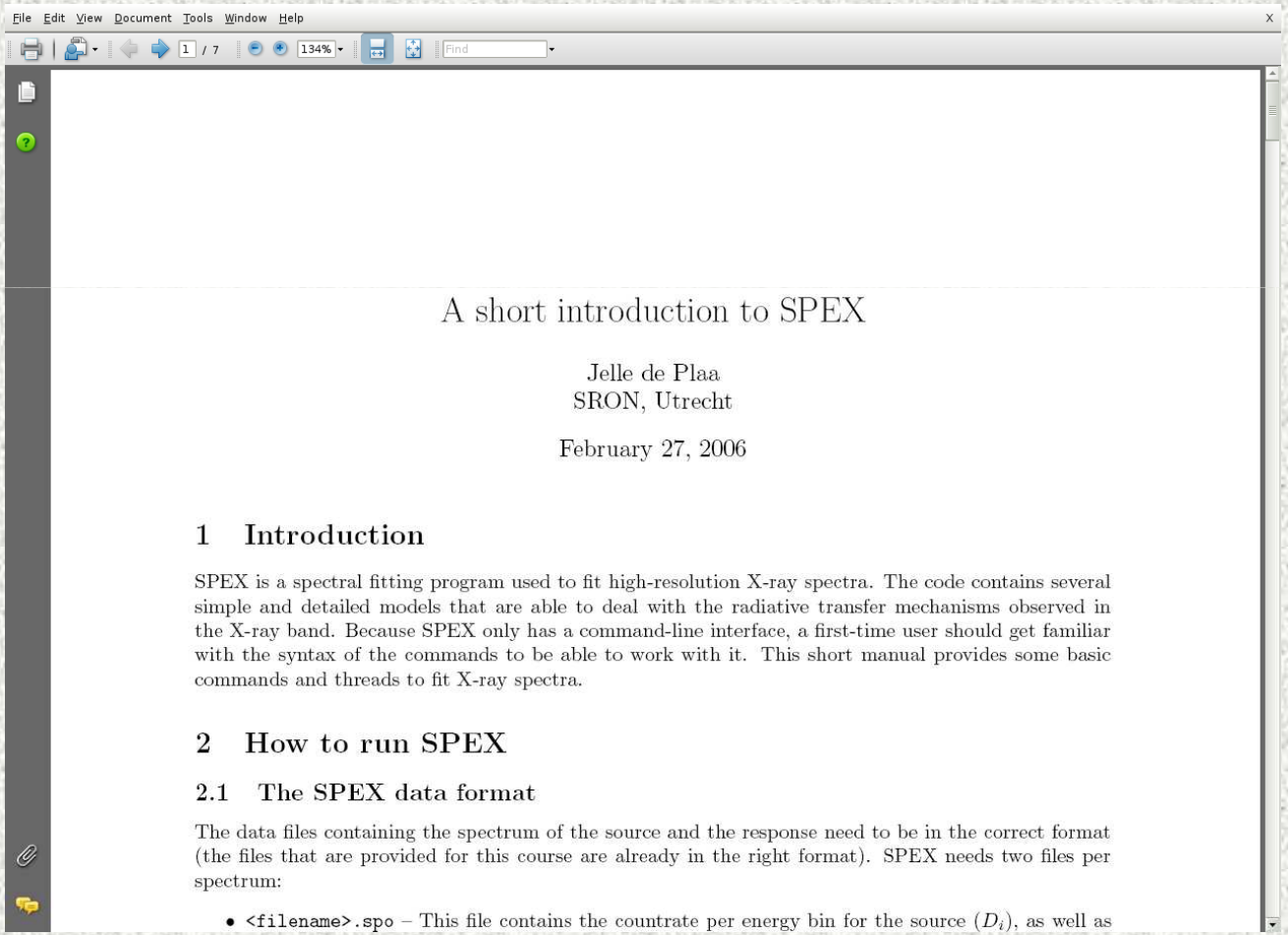
SPEX Manual

http://www.sron.nl/files/HEA/SPEX/manuals/manual.pdf



Quick-start documents

http://www.sron.nl/files/HEA/SPEX/manuals/spex_intro.pdf



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A short introduction to SPEX

Jelle de Plaa
SRON, Utrecht

February 27, 2006

1 Introduction

SPEX is a spectral fitting program used to fit high-resolution X-ray spectra. The code contains several simple and detailed models that are able to deal with the radiative transfer mechanisms observed in the X-ray band. Because SPEX only has a command-line interface, a first-time user should get familiar with the syntax of the commands to be able to work with it. This short manual provides some basic commands and threads to fit X-ray spectra.

2 How to run SPEX

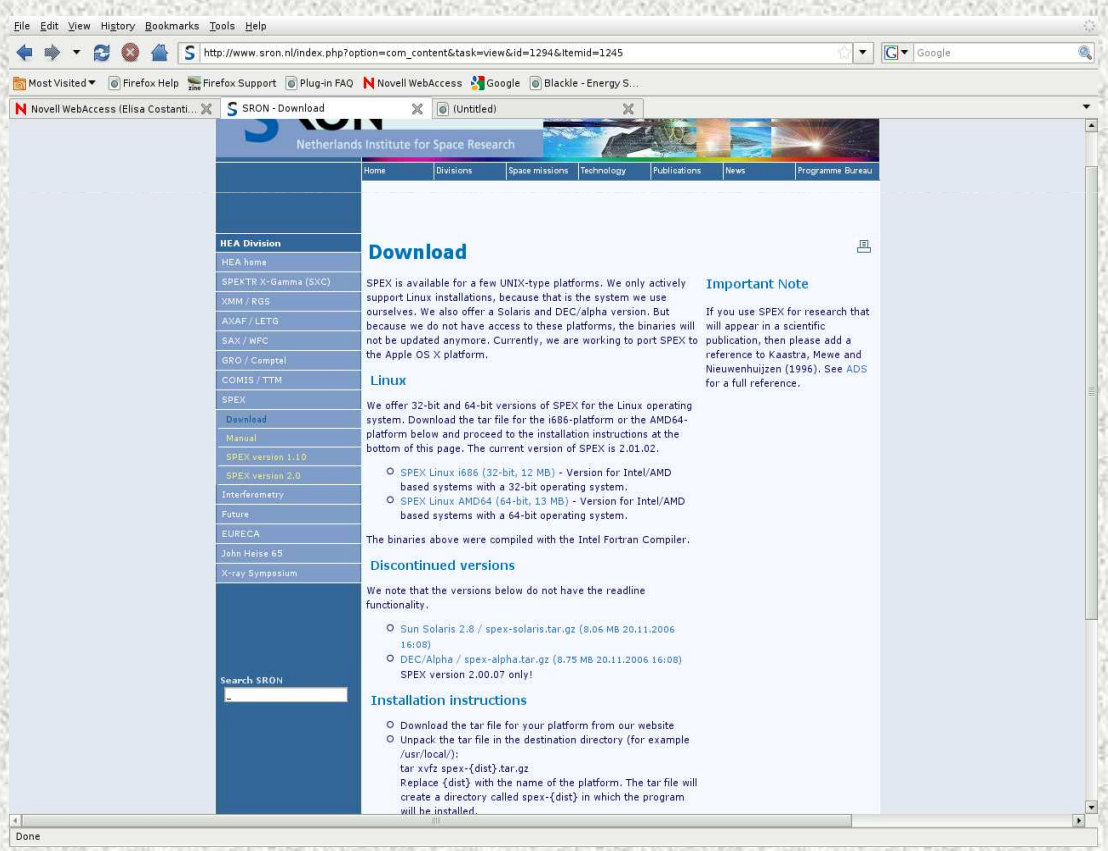
2.1 The SPEX data format

The data files containing the spectrum of the source and the response need to be in the correct format (the files that are provided for this course are already in the right format). SPEX needs two files per spectrum:

- `<filename>.spo` – This file contains the countrate per energy bin for the source (D_i), as well as

Downloading SPEX

- The latest version of SPEX is available for LINUX (and MAC-OS)
- Older version available for SOLARIS and Alpha-Dec



Easy installation: download a tar archive
Unpack the tar
Source the script
(bash- or c-shell)

→ The environment variables are set

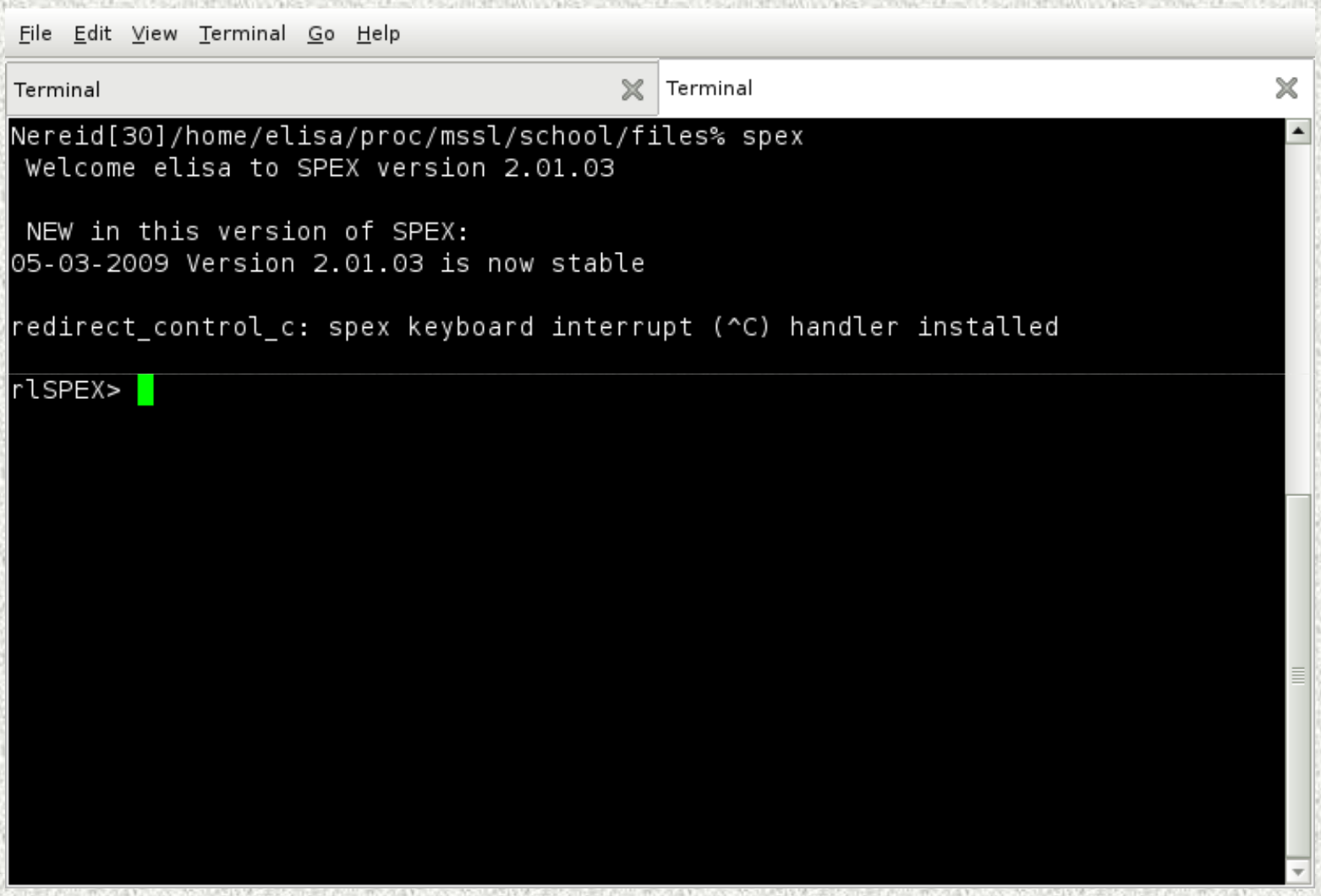
→
TRAFO
SPEX
Are ready for use!

Step 1: using TRAFO

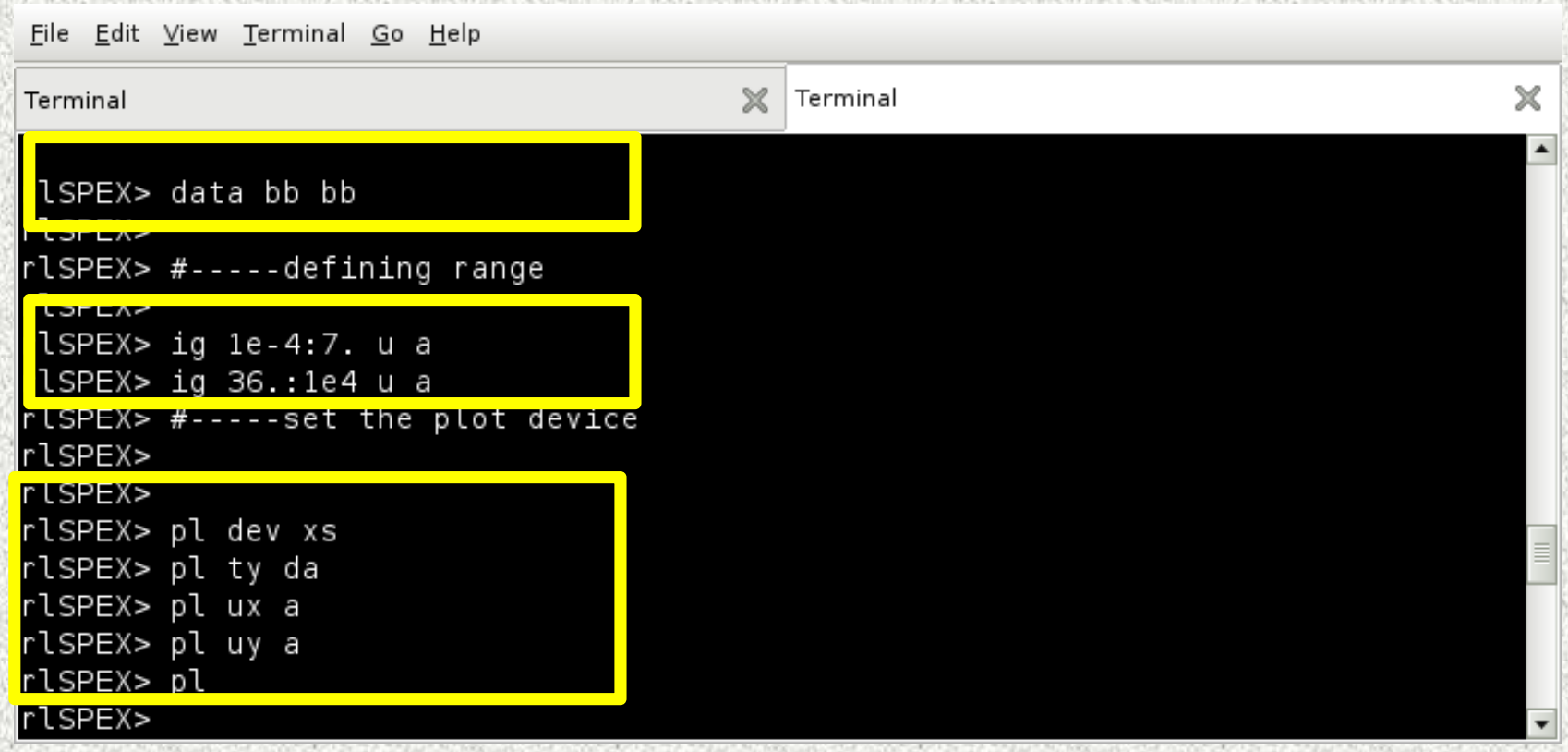
- TRAFO converts normal fits files into SPEX format → trimmed, slimmer fits files.

  → new spectrum & response matrix
- Inputs:
  - Original spectrum (either binned or unbinned)
  - Background
  - Effective area
  - Response matrix

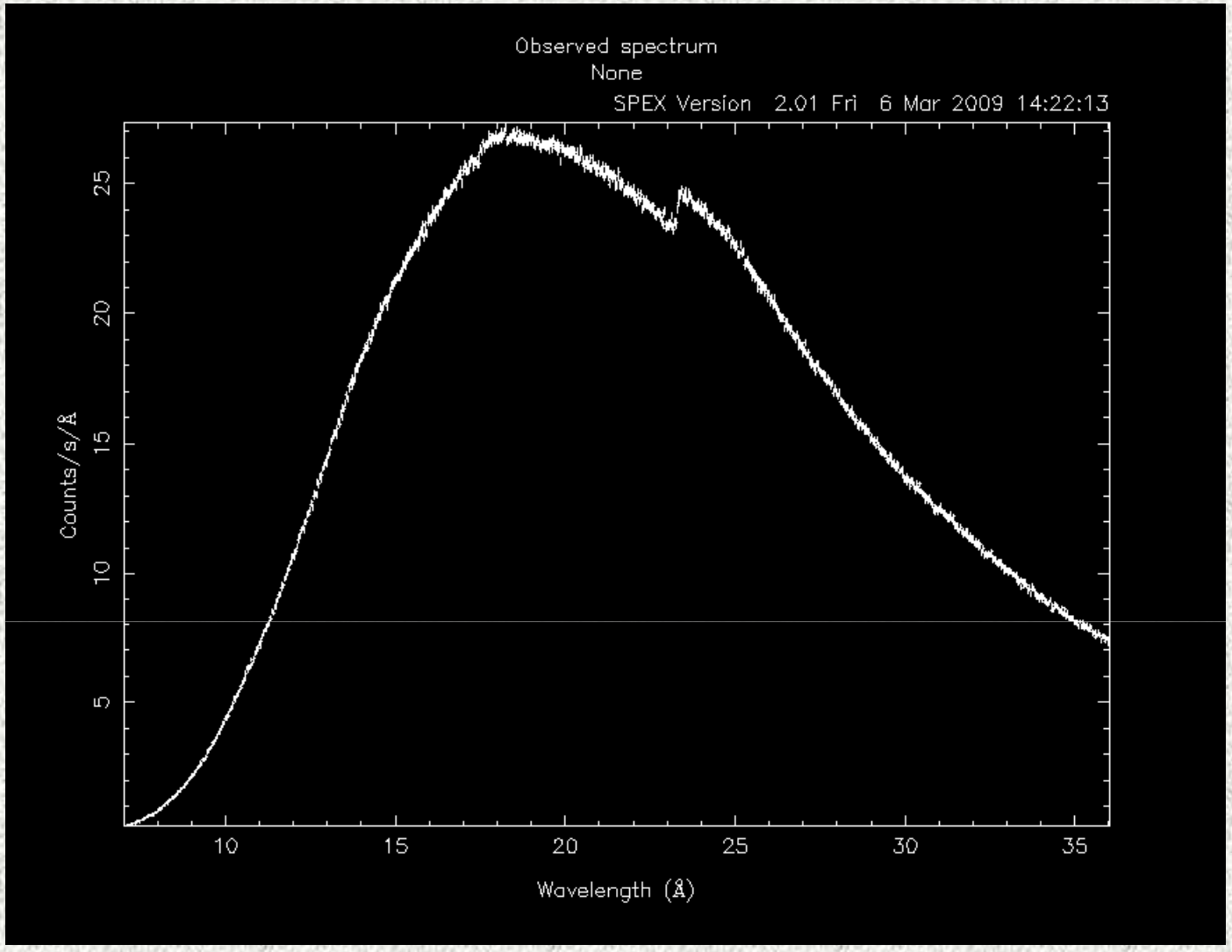
Example: AGN
Galactic abs*black body



Example 1: fitting a black body



- Spectrum and response matrix are names bb.spo and bb.res
- Use the RGS band: 7:35 Angstrom
- Display the data in Angstrom



Save the plot:

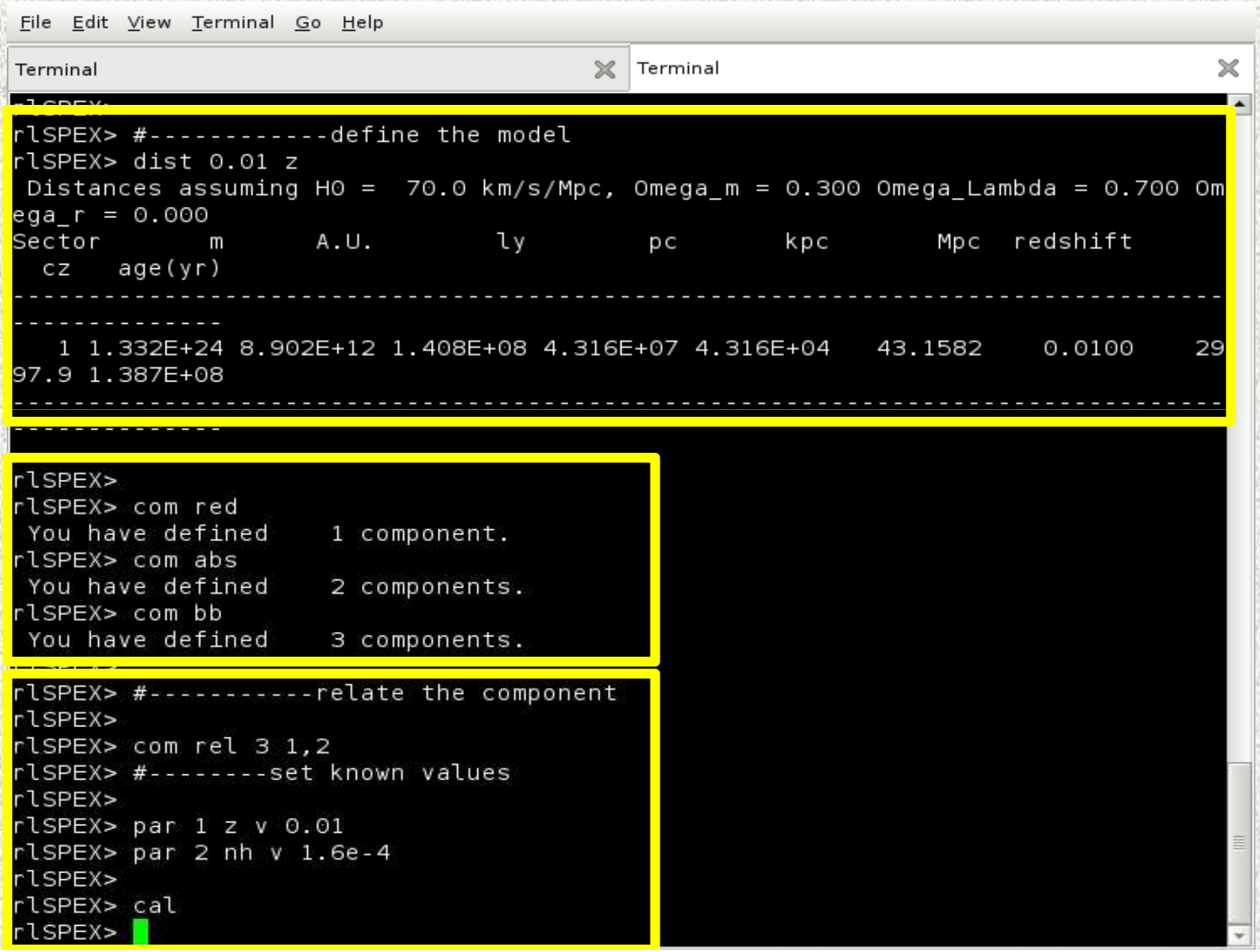
SPEX> pl x lin

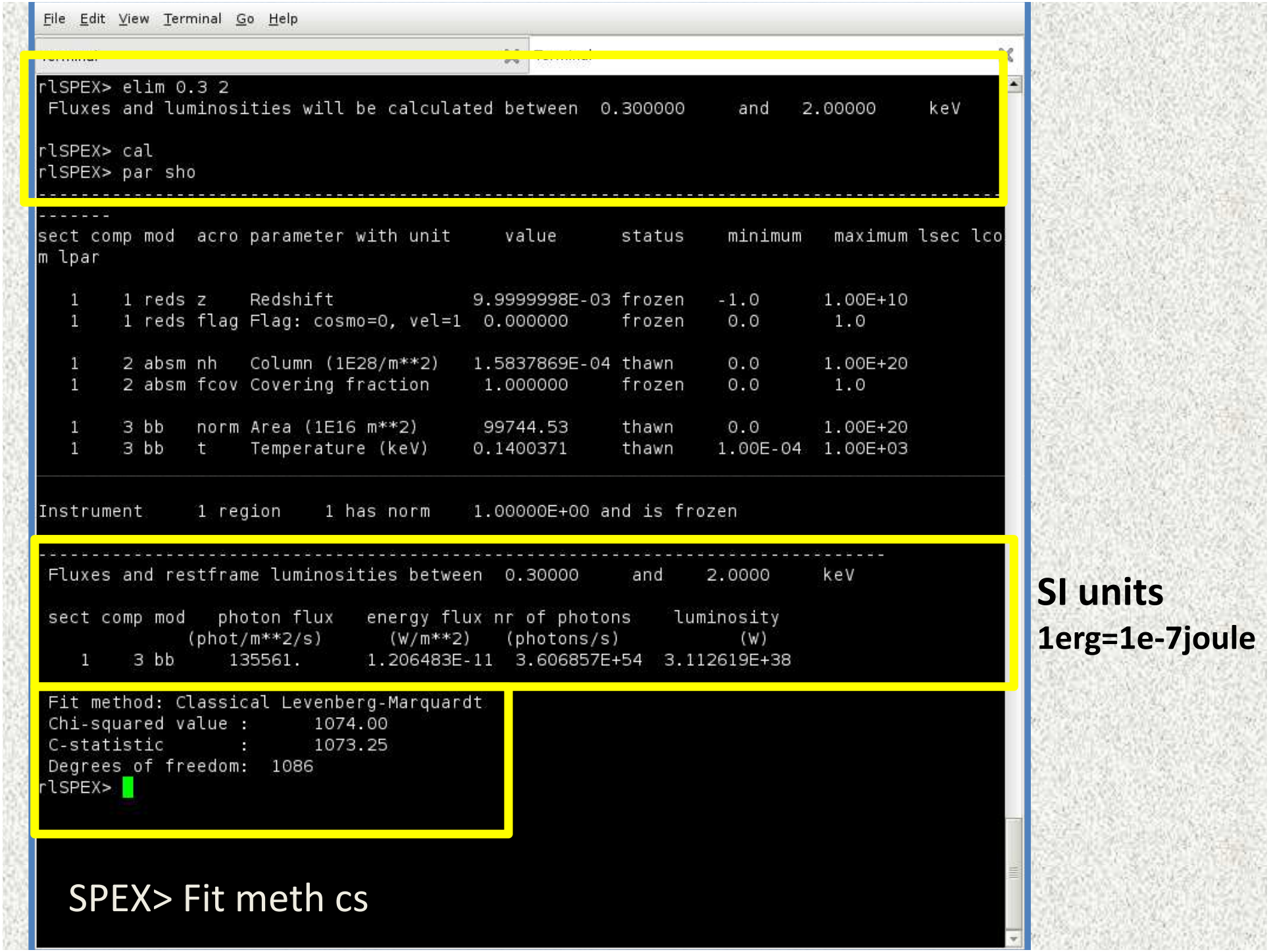
SPEX> pl y lin

SPEX> plot adump data_plot

→ data_plot.qdp ready for post processing with pgplot

Fitting the spectrum





SI units

1erg=1e-7joule

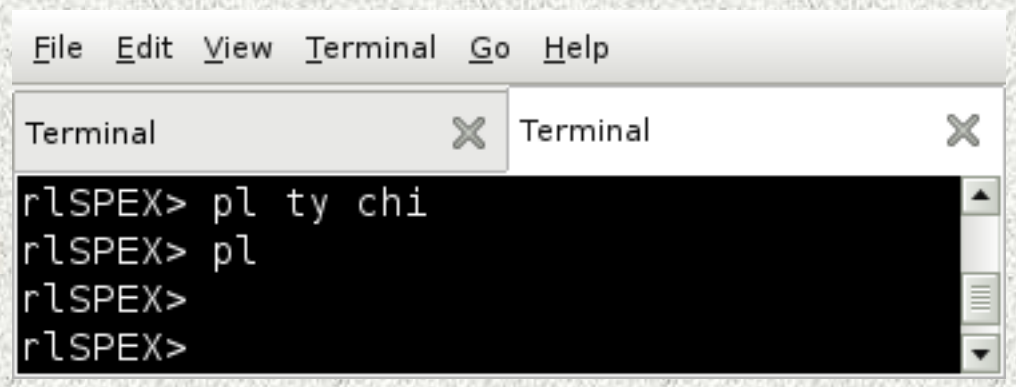
Other useful types of plotting

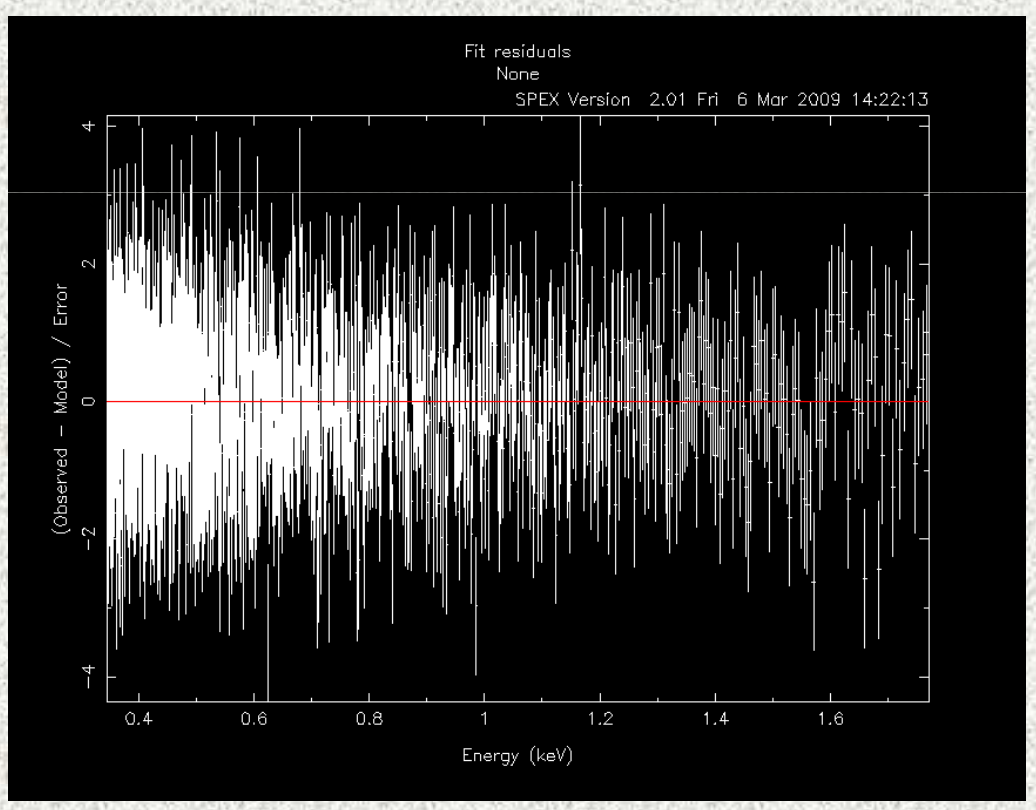
- **pl ty chi** → residuals in terms of χ
  - **pl uy rel** → residuals relative to the model (data-model)/model

- **pl ty model** → plot of the current model (ph m^{-2} s^{-1} Ang^{-1})

- **pl ty data**
  - **pl uy fa** → cts s^{-1} m^{-2} Ang^{-1}
  - **pl uy counts** → number of counts in a particular emission feature

! A useful command file is in your exercise kit: plot_rgs.pro



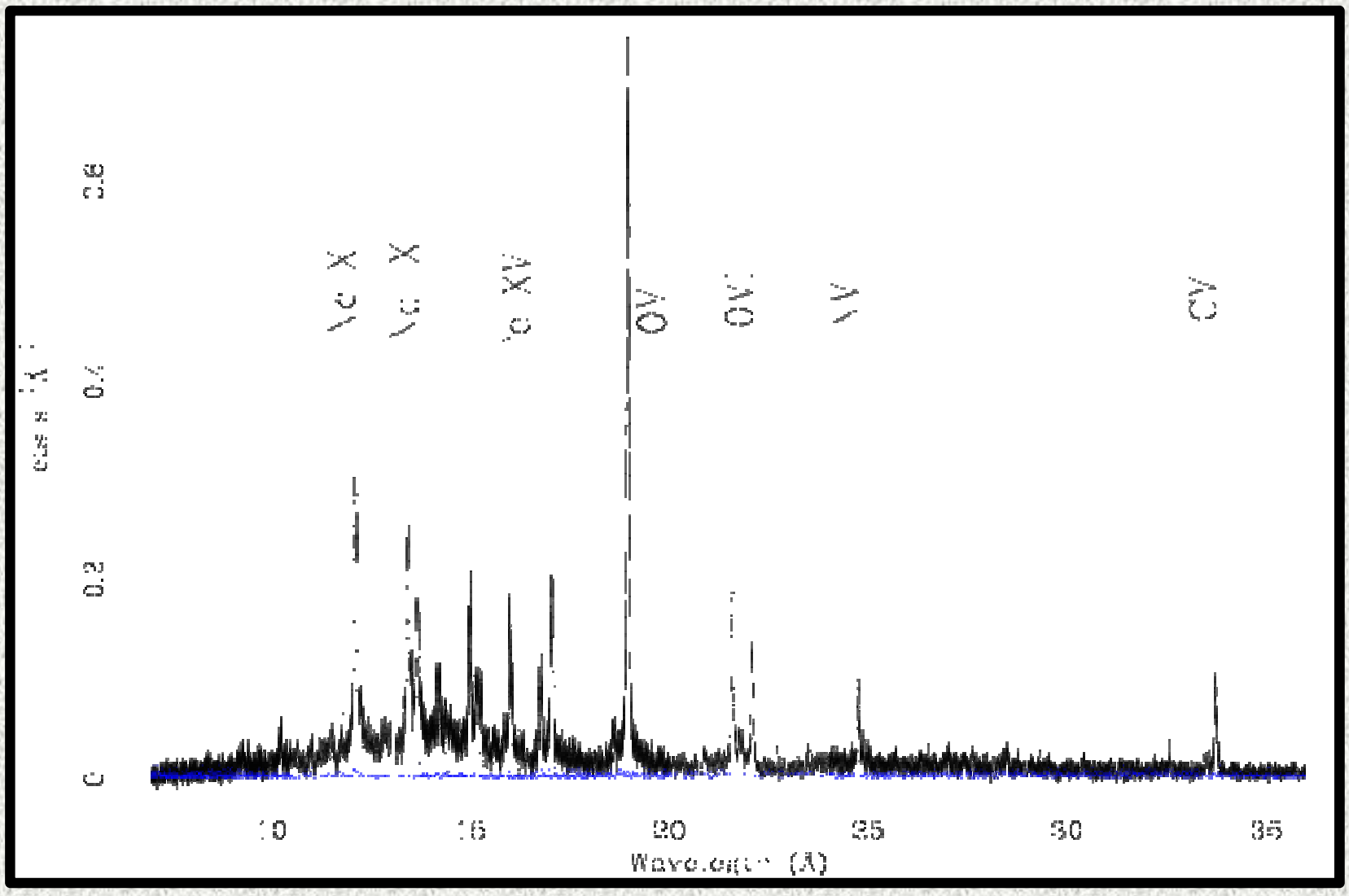


A “live” example
Fitting a
star spectrum: AU Microscopii

- AU Mic is a cool nearby star (9pc), with a thermal spectrum.
- Plasma at different temperatures (coming from different loops of the stellar corona) produces a wealth of lines in the RGS band.

→ (Multiple) Collisionally ionized emission model, CIE (see also E. Behar talk)

The RGS spectrum of AU Mic



CIE model parameters

```
rlSPEX> com cie
 You have defined    1 component.
rlSPEX> par sho
```

sect	comp	mod	acro	parameter with unit	value	status	minimum	maximum	lsec
1	1	cie	norm	ne nX V (1E64/m**3)	1.000000	thawn	0.	1.00E+20	
1	1	cie	t	Temperature (keV)	1.000000	thawn	5.00E-04	1.00E+03	
1	1	cie	sig	Sigma (log T)	0.00000	frozen	0.	1.00E+04	
1	1	cie	ed	El dens (1E20/m**3)	9.9999998E-15	frozen	1.00E-22	1.00E+10	
1	1	cie	it	Ion temp (keV)	1.000000	frozen	1.00E-04	1.00E+07	
1	1	cie	rt	T(balance) / T(spec)	1.000000	frozen	1.00E-04	1.00E+04	
1	1	cie	vmic	Microturb vel (km/s)	0.00000	frozen	0.	3.00E+05	
1	1	cie	ref	Reference atom	1.000000	frozen	1.0	30.	
1	1	cie	01	Abundance H	1.000000	frozen	0.	1.00E+10	
1	1	cie	02	Abundance He	1.000000	frozen	0.	1.00E+10	
1	1	cie	03	Abundance Li	1.000000	frozen	0.	1.00E+10	
1	1	cie	04	Abundance Be	1.000000	frozen	0.	1.00E+10	
1	1	cie	05	Abundance B	1.000000	frozen	0.	1.00E+10	
1	1	cie	06	Abundance C	1.000000	frozen	0.	1.00E+10	
1	1	cie	07	Abundance N	1.000000	frozen	0.	1.00E+10	
1	1	cie	08	Abundance O	1.000000	frozen	0.	1.00E+10	
1	1	cie	09	Abundance F	1.000000	frozen	0.	1.00E+10	
1	1	cie	10	Abundance Ne	1.000000	frozen	0.	1.00E+10	
1	1	cie	11	Abundance Na	1.000000	frozen	0.	1.00E+10	
1	1	cie	12	Abundance Mg	1.000000	frozen	0.	1.00E+10	
1	1	cie	13	Abundance Al	1.000000	frozen	0.	1.00E+10	
1	1	cie	14	Abundance Si	1.000000	frozen	0.	1.00E+10	
1	1	cie	15	Abundance P	1.000000	frozen	0.	1.00E+10	
1	1	cie	16	Abundance S	1.000000	frozen	0.	1.00E+10	
1	1	cie	17	Abundance Cl	1.000000	frozen	0.	1.00E+10	
1	1	cie	18	Abundance Ar	1.000000	frozen	0.	1.00E+10	
1	1	cie	19	Abundance K	1.000000	frozen	0.	1.00E+10	
1	1	cie	20	Abundance Ca	1.000000	frozen	0.	1.00E+10	
1	1	cie	21	Abundance Sc	1.000000	frozen	0.	1.00E+10	
1	1	cie	22	Abundance Ti	1.000000	frozen	0.	1.00E+10	
1	1	cie	23	Abundance V	1.000000	frozen	0.	1.00E+10	
1	1	cie	24	Abundance Cr	1.000000	frozen	0.	1.00E+10	
1	1	cie	25	Abundance Mn	1.000000	frozen	0.	1.00E+10	
1	1	cie	26	Abundance Fe	1.000000	frozen	0.	1.00E+10	
1	1	cie	27	Abundance Co	1.000000	frozen	0.	1.00E+10	
1	1	cie	28	Abundance Ni	1.000000	frozen	0.	1.00E+10	
1	1	cie	29	Abundance Cu	1.000000	frozen	0.	1.00E+10	
1	1	cie	30	Abundance Zn	1.000000	frozen	0.	1.00E+10	
1	1	cie	file	File electr.distrib.					

Emission measure

CIE model parameters

```
rlSPEX> com cie
 You have defined    1 component.
rlSPEX> par sho
-------------------------------------------------------------------------------------
sect comp mod  acro parameter with unit     value      status    minimum   maximum lsec

   1    1 cie  norm ne nX V (1E64/m**3)   1.000000     thawn      0.      1.00E+20
   1    1 cie  t    Temperature (keV)      1.000000     thawn    5.00E-04  1.00E+03
   1    1 cie  sig  Sigma (log T)          0.00000     frozen     0.      1.00E+04
   1    1 cie  ed   El. dens (1E20/m**3) 9.9999998E-15 frozen   1.00E-22  1.00E+10
   1    1 cie  it   Ion temp  (keV)       1.000000     frozen   1.00E-04  1.00E+07
   1    1 cie  rt   T(balance) / T(spec)  1.000000     frozen   1.00E-04  1.00E+04
   1    1 cie  vmic Microturb vel (km/s)   0.00000     frozen     0.      3.00E+05
   1    1 cie  ref  Reference atom        1.000000     frozen    1.0       30.
   1    1 cie  01   Abundance H           1.000000     frozen     0.      1.00E+10
   1    1 cie  02   Abundance He          1.000000     frozen     0.      1.00E+10
   1    1 cie  03   Abundance Li          1.000000     frozen     0.      1.00E+10
   1    1 cie  04   Abundance Be          1.000000     frozen     0.      1.00E+10
   1    1 cie  05   Abundance B           1.000000     frozen     0.      1.00E+10
   1    1 cie  06   Abundance C           1.000000     frozen     0.      1.00E+10
   1    1 cie  07   Abundance N           1.000000     frozen     0.      1.00E+10
   1    1 cie  08   Abundance O           1.000000     frozen     0.      1.00E+10
   1    1 cie  09   Abundance F           1.000000     frozen     0.      1.00E+10
   1    1 cie  10   Abundance Ne          1.000000     frozen     0.      1.00E+10
   1    1 cie  11   Abundance Na          1.000000     frozen     0.      1.00E+10
   1    1 cie  12   Abundance Mg          1.000000     frozen     0.      1.00E+10
   1    1 cie  13   Abundance Al          1.000000     frozen     0.      1.00E+10
   1    1 cie  14   Abundance Si          1.000000     frozen     0.      1.00E+10
   1    1 cie  15   Abundance P           1.000000     frozen     0.      1.00E+10
   1    1 cie  16   Abundance S           1.000000     frozen     0.      1.00E+10
   1    1 cie  17   Abundance Cl          1.000000     frozen     0.      1.00E+10
   1    1 cie  18   Abundance Ar          1.000000     frozen     0.      1.00E+10
   1    1 cie  19   Abundance K           1.000000     frozen     0.      1.00E+10
   1    1 cie  20   Abundance Ca          1.000000     frozen     0.      1.00E+10
   1    1 cie  21   Abundance Sc          1.000000     frozen     0.      1.00E+10
   1    1 cie  22   Abundance Ti          1.000000     frozen     0.      1.00E+10
   1    1 cie  23   Abundance V           1.000000     frozen     0.      1.00E+10
   1    1 cie  24   Abundance Cr          1.000000     frozen     0.      1.00E+10
   1    1 cie  25   Abundance Mn          1.000000     frozen     0.      1.00E+10
   1    1 cie  26   Abundance Fe          1.000000     frozen     0.      1.00E+10
   1    1 cie  27   Abundance Co          1.000000     frozen     0.      1.00E+10
   1    1 cie  28   Abundance Ni          1.000000     frozen     0.      1.00E+10
   1    1 cie  29   Abundance Cu          1.000000     frozen     0.      1.00E+10
   1    1 cie  30   Abundance Zn          1.000000     frozen     0.      1.00E+10
   1    1 cie  file File electr.distrib.
```

Temperatures:

-- Electron T_e

-- Ionic T_i → line thermal broadening (dependence on the thermal velocity of the ions and also on ion mass)

-- equilibrium T_b
→In CIE $T_b/T_e=1$

Note: for non-equilibrium use the NEI model.

CIE model parameters

```
rlSPEX> com cie
 You have defined    1 component.
rlSPEX> par sho
-------------------------------------------------------------------------------
sect comp mod  acro parameter with unit     value      status    minimum   maximum lsec

   1    1 cie  norm ne nX V (1E64/m**3)   1.000000     thawn      0.      1.00E+20
   1    1 cie  t    Temperature (keV)      1.000000     thawn    5.00E-04  1.00E+03
   1    1 cie  sig  Sigma (log T)          0.00000     frozen     0.      1.00E+04
   1    1 cie  ed   El  dens (1E20/m**3) 9.9999998E-15 frozen   1.00E-22  1.00E+10
   1    1 cie  it   Ion temp  (keV)       1.000000     frozen   1.00E-04  1.00E+07
   1    1 cie  rt   T(balance) / T(spec)  1.000000     frozen   1.00E-04  1.00E+04
   1    1 cie  vmic Microturb vel (km/s)   0.00000     frozen     0.      3.00E+05
   1    1 cie  ref  Reference atom         1.000000     frozen    1.0       30.
   1    1 cie  01   Abundance H            1.000000     frozen     0.      1.00E+10
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   1    1 cie  05   Abundance B            1.000000     frozen     0.      1.00E+10
   1    1 cie  06   Abundance C            1.000000     frozen     0.      1.00E+10
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   1    1 cie  08   Abundance O            1.000000     frozen     0.      1.00E+10
   1    1 cie  09   Abundance F            1.000000     frozen     0.      1.00E+10
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   1    1 cie  16   Abundance S            1.000000     frozen     0.      1.00E+10
   1    1 cie  17   Abundance Cl           1.000000     frozen     0.      1.00E+10
   1    1 cie  18   Abundance Ar           1.000000     frozen     0.      1.00E+10
   1    1 cie  19   Abundance K            1.000000     frozen     0.      1.00E+10
   1    1 cie  20   Abundance Ca           1.000000     frozen     0.      1.00E+10
   1    1 cie  21   Abundance Sc           1.000000     frozen     0.      1.00E+10
   1    1 cie  22   Abundance Ti           1.000000     frozen     0.      1.00E+10
   1    1 cie  23   Abundance V            1.000000     frozen     0.      1.00E+10
   1    1 cie  24   Abundance Cr           1.000000     frozen     0.      1.00E+10
   1    1 cie  25   Abundance Mn           1.000000     frozen     0.      1.00E+10
   1    1 cie  26   Abundance Fe           1.000000     frozen     0.      1.00E+10
   1    1 cie  27   Abundance Co           1.000000     frozen     0.      1.00E+10
   1    1 cie  28   Abundance Ni           1.000000     frozen     0.      1.00E+10
   1    1 cie  29   Abundance Cu           1.000000     frozen     0.      1.00E+10
   1    1 cie  30   Abundance Zn           1.000000     frozen     0.      1.00E+10
   1    1 cie  file File electr.distrib.
```

Width of the temperature (Gaussian) distribution

$\sigma_T = 0 \rightarrow$ plasma is isothermal

Line broadening due to **microturbulence:**

$V_{mic} = \sqrt{2}\,\sigma_v$ where σ_v is the Velocity dispersion along the line of sight

CIE model parameters

```
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```

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1	1	cie	t	Temperature (keV)	1.000000	thawn	5.00E-04	1.00E+03	
1	1	cie	sig	Sigma (log T)	0.00000	frozen	0.	1.00E+04	
1	1	cie	ed	El. dens (1E20/m**3)	9.9999998E-15	frozen	1.00E-22	1.00E+10	
1	1	cie	it	Ion temp (keV)	1.000000	frozen	1.00E-04	1.00E+07	
1	1	cie	rt	T(balance) / T(spec)	1.000000	frozen	1.00E-04	1.00E+04	
1	1	cie	vmic	Microturb vel (km/s)	0.00000	frozen	0.	3.00E+05	
1	1	cie	ref	Reference atom	1.000000	frozen	1.0	30.	
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1	1	cie	02	Abundance He	1.000000	frozen	0.	1.00E+10	
1	1	cie	03	Abundance Li	1.000000	frozen	0.	1.00E+10	
1	1	cie	04	Abundance Be	1.000000	frozen	0.	1.00E+10	
1	1	cie	05	Abundance B	1.000000	frozen	0.	1.00E+10	
1	1	cie	06	Abundance C	1.000000	frozen	0.	1.00E+10	
1	1	cie	07	Abundance N	1.000000	frozen	0.	1.00E+10	
1	1	cie	08	Abundance O	1.000000	frozen	0.	1.00E+10	
1	1	cie	09	Abundance F	1.000000	frozen	0.	1.00E+10	
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1	1	cie	11	Abundance Na	1.000000	frozen	0.	1.00E+10	
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1	1	cie	16	Abundance S	1.000000	frozen	0.	1.00E+10	
1	1	cie	17	Abundance Cl	1.000000	frozen	0.	1.00E+10	
1	1	cie	18	Abundance Ar	1.000000	frozen	0.	1.00E+10	
1	1	cie	19	Abundance K	1.000000	frozen	0.	1.00E+10	
1	1	cie	20	Abundance Ca	1.000000	frozen	0.	1.00E+10	
1	1	cie	21	Abundance Sc	1.000000	frozen	0.	1.00E+10	
1	1	cie	22	Abundance Ti	1.000000	frozen	0.	1.00E+10	
1	1	cie	23	Abundance V	1.000000	frozen	0.	1.00E+10	
1	1	cie	24	Abundance Cr	1.000000	frozen	0.	1.00E+10	
1	1	cie	25	Abundance Mn	1.000000	frozen	0.	1.00E+10	
1	1	cie	26	Abundance Fe	1.000000	frozen	0.	1.00E+10	
1	1	cie	27	Abundance Co	1.000000	frozen	0.	1.00E+10	
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1	1	cie	30	Abundance Zn	1.000000	frozen	0.	1.00E+10	
1	1	cie	file	File electr.distrib.					

Electron density

Lines which are sensitive to density will be adjusted in normalization

CIE model parameters

```
rlSPEX> com cie
 You have defined    1 component.
rlSPEX> par sho
-------------------------------------------------------------------------------------------
sect comp mod  acro parameter with unit     value      status    minimum   maximum lsec

   1    1 cie  norm ne nX V (1E64/m**3)   1.000000     thawn      0.      1.00E+20
   1    1 cie  t    Temperature (keV)     1.000000     thawn    5.00E-04  1.00E+03
   1    1 cie  sig  Sigma (log T)          0.00000     frozen     0.      1.00E+04
   1    1 cie  ed   El  dens (1E20/m**3) 9.9999998E-15 frozen   1.00E-22  1.00E+10
   1    1 cie  it   Ion temp  (keV)       1.000000     frozen   1.00E-04  1.00E+07
   1    1 cie  rt   T(balance) / T(spec)  1.000000     frozen   1.00E-04  1.00E+04
   1    1 cie  vmic Microturb vel (km/s)   0.00000     frozen     0.      3.00E+05
   1    1 cie  ref  Reference atom         1.000000     frozen    1.0       30.
   1    1 cie  01   Abundance H            1.000000     frozen     0.      1.00E+10
   1    1 cie  02   Abundance He           1.000000     frozen     0.      1.00E+10
   1    1 cie  03   Abundance Li           1.000000     frozen     0.      1.00E+10
   1    1 cie  04   Abundance Be           1.000000     frozen     0.      1.00E+10
   1    1 cie  05   Abundance B            1.000000     frozen     0.      1.00E+10
   1    1 cie  06   Abundance C            1.000000     frozen     0.      1.00E+10
   1    1 cie  07   Abundance N            1.000000     frozen     0.      1.00E+10
   1    1 cie  08   Abundance O            1.000000     frozen     0.      1.00E+10
   1    1 cie  09   Abundance F            1.000000     frozen     0.      1.00E+10
   1    1 cie  10   Abundance Ne           1.000000     frozen     0.      1.00E+10
   1    1 cie  11   Abundance Na           1.000000     frozen     0.      1.00E+10
   1    1 cie  12   Abundance Mg           1.000000     frozen     0.      1.00E+10
   1    1 cie  13   Abundance Al           1.000000     frozen     0.      1.00E+10
   1    1 cie  14   Abundance Si           1.000000     frozen     0.      1.00E+10
   1    1 cie  15   Abundance P            1.000000     frozen     0.      1.00E+10
   1    1 cie  16   Abundance S            1.000000     frozen     0.      1.00E+10
   1    1 cie  17   Abundance Cl           1.000000     frozen     0.      1.00E+10
   1    1 cie  18   Abundance Ar           1.000000     frozen     0.      1.00E+10
   1    1 cie  19   Abundance K            1.000000     frozen     0.      1.00E+10
   1    1 cie  20   Abundance Ca           1.000000     frozen     0.      1.00E+10
   1    1 cie  21   Abundance Sc           1.000000     frozen     0.      1.00E+10
   1    1 cie  22   Abundance Ti           1.000000     frozen     0.      1.00E+10
   1    1 cie  23   Abundance V            1.000000     frozen     0.      1.00E+10
   1    1 cie  24   Abundance Cr           1.000000     frozen     0.      1.00E+10
   1    1 cie  25   Abundance Mn           1.000000     frozen     0.      1.00E+10
   1    1 cie  26   Abundance Fe           1.000000     frozen     0.      1.00E+10
   1    1 cie  27   Abundance Co           1.000000     frozen     0.      1.00E+10
   1    1 cie  28   Abundance Ni           1.000000     frozen     0.      1.00E+10
   1    1 cie  29   Abundance Cu           1.000000     frozen     0.      1.00E+10
   1    1 cie  30   Abundance Zn           1.000000     frozen     0.      1.00E+10
   1    1 cie  file File electr.distrib.
```

Abundances

Deafult is set to solar (Anders & Grevesse 89)

Change abundances:
SPEX> abu #a

Reference atom is H, but for spectra with strong lines (and weak continuum) it's better to set the ref to the strongest line (Fe)