Absorption models in SPEX

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Overview

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Introduction

- Collisionally ionized absorption characterized by temperature of the plasma. An example is Galactic absorption or absorption in the host galaxy.
- Photo-ionized absorption characterized by the ionization parameter, and is the absorption mechanism observed in AGN outflows, i.e. warm absorbers.
- The difference in ionization mechanism can be seen by comparing differences in higher order line strengths of an ion and the line ratios in the triplets such as O VII.

Introduction

- Ionization parameter used in SPEX is ξ=L/nr², with L the source luminosity, n the density and r the distance between the ionizing source and the absorbing gas. ξ and L are determined from observations, but n and r are unknown. SPEX uses log values in 10⁻⁹ Wm (ergs cm s⁻¹). This definition is the same as used in XSTAR.
- Alternative definition: U=Q/4πr²cn, Q the number of hydrogen ionizing photons emitted by the source, n the density and c the speed of light. This definition is used in CLOUDY and is dimensionless.
- Both definitions depend on the input spectral energy distribution.

Pressure equilibrium: S-curve

- Some scenarios assume that the clouds, which produce the absorption lines observed, are in pressure equilibrium with the surrounding higher ionized gas. If so, the cloud is stable and thus can survive for longer.
- The ionization parameter for constant pressure, $\Xi = L/(4\pi cr^2 P) = 9.61 \times 10^3 \xi/T$, with P pressure, T temperature.
- Cloudy and XSTAR calculate E versus T, S-curves, for a spectral energy distribution. From this curve, if the ionization parameters lie on the stable branch then the absorbers are in pressure equilibrium.



For NGC 5548, none of the components are in pressure equilibrium in this case.

Absm model

- The model calculates the transmission of a neutral gas with cosmic abundances (Morrison and McCammon 1983).
- Often used for modelling absorption in our own Galaxy toward the observed object.
- Model includes only continuum absorption.
- Abundances cannot be changed.
- Location of some edges is not as accurate as high resolution spectroscopy demands.

Absm model

- Free parameters are:
- Total hydrogen column density
- The covering factor of the absorber
- Model with no absorption (black) and with a column density of 10²⁴ m⁻² (red).



Absm model



- Absm model for 2 different hydrogen column density.
- The longer wavelengths are much more absorbed than the shorter wavelengths.

- Collisional ionisation equilibrium absorption model.
- The temperature determines the ionisation balance and with the abundance and hydrogen column density, the ionic column densities are calculated.
- From the column densities the transmission is then calculated.
- This model includes line and continuum opacities.
- Use for fitting absorption from our and/or the host galaxy. Also use for warm hot intergalactic medium absorption, if the density is high enough.
- The line profiles used are Voigt profiles.

Hot Model

• Parameters are:

Total hydrogen column density Electron temperature

Covering factor

Ratio of ionization balance (rt)

Systematic velocity (red/or blueshift velocity)

Velocity broadening (v)

RMS velocity of a blend of velocity components (rms)

Velocity distance between the velocity components (dv)

Reference element compared to which abundances are calculated (ref)

Abundances for H to Zn (1 to 30), standard values are cosmic abundances.

Filename for non-thermal electron distributions



• Specific parameters:

Ratio of ionization balance: $R_b = T_b/T_e = 1$ for a plasma in equilibrium.

R_b<1 mimics an ionizing plasma.

Rb>1 mimics a recombining plasma.

To Approximate a neutral gas use T=0.5 eV.





T=1 keV, different hydrogen column density.

Changing the abundance of oxygen and iron, note the very similar absorption edge at ~17 Å.

- Comparing the absorption for different temperatures.
- All absorption components have a hydrogen column density of 10²⁴ m⁻².
- Note that the hotter, the less absorption occurs, and the shorter the wavelength at which it occurs.
- Note the different lines that appear for different temperatures.



- This and following models are for photo-ionized absorption.
- Transmission is calculated for a thin slab of gas.
- The column density for each ion is a free parameter, thus one can fit ion per ion, but per ion all lines are included.
- The model calculates the line and continuum absorption.
- Thompson scattering by free electrons is included, as are fully stripped ions. However, note that as the Thompson scattering is independent of which ion the electrons came from, the column density determined for bare ions is not well constrained.
- Other parameters are tied for all ions: covering factor, velocity shift, velocity broadening, RMS velocity broadening for multiple velocity components, velocity distance between components.
- Multiple slab models can be used, rather than using the RMS broadening, or if one suspects the outflow velocity/broadening might be ionization state dependent.



- Absorption model for C VI, with a column density of 10²⁰ (black) and 10²² (red) m⁻².
- Note the large difference in continuum absorption, however in real spectra with nontrivial continua, edges are hard to discern, albeit present.



Effect of assuming a blueshift of the lines for the C VI Lyman series.

Effects of velocity broadening on the modeled C VI L α line.



Absorption spectrum assuming all frequently observed ions have a column density of 10^{20} m⁻². Note that each ion can have a different column density, which can be fit separately or simultaneously.

Fitting or plotting ion per ion allows for easy identification of the observed lines. However, note that quite a few lines with current spectral resolution are blends of several ions.



- Black curve: same model as previously, red curve: Assuming that the slab of gas only covers 75% of the continuum emission.
- Main difference is in the continuum level and shape.



Observational example



- Chandra MEG and LETGS data of NGC 5548. Note the difference in resolution between both spectra.
- The Ne X Lyα is broadened beyond the MEG spectral resolution.

Observational results



- Chandra LETGS spectrum of NGC 5548.
- Note the many absorption lines from different elements as well as the N VI triplet.
- The velocity resolution increases with wavelength.

Xabs model

- Photo-ionised absorption model: calculates the transmission of a slab of material where all ionic column densities are tied through a photo-ionisation model.
- Many fewer parameters than slab model, and ions with weak lines hard to detect individually are automatically included.
- Possibility to give SPEX a file with the appropriate photo-ionisation balance, i.e. ascii file containing a list of ionic column densities versus ionisation parameter, if spectral energy distribution is significantly different from that of NGC 5548.

Xabs model

- Special parameters are: ionization parameter ξ hydrogen column density
- Other parameters are abundances and velocity parameters and covering factor.
- Note that the higher the ionization parameter the weaker the observed absorption, hence only large column density high ionization absorbers are detectable.



Xabs model



- Multiple xabs components can be used (here 2 with logξ=0.5 and 2 in 10⁻⁹ W m).
- Each xabs component has potentially its own velocity, abundance and covering factor parameters in addition to hydrogen column density and ionization parameter.
- One can tie for instance the abundances between different xabs components.

Xabs model: output

Ion		Column (1E28/m**2)	log column (/m**2)
н	I	1.047E-09	19.020
н	II	1.000E-04	24.000
He	I	2.042E-13	15.310
He	II	1.778E-08	20.250
He	Ш	8.511E-06	22.930
С	II	1.905E-15	13.280
С	Ш	3.162E-12	16.500
С	IV	2.089E-10	18.320
С	V	1.096E-08	20.040
С	VI	1.148E-08	20.060
С	VII	1.995E-09	19.300
Ν	II	1.950E-16	12.290
N	Ш	6.457E-13	15.810
Ν	IV	5.248E-11	17.720
Ν	V	6.166E-10	18.790
N	VI	5.888B-09	19.770
N	VII	1.862E-09	19.270
Ν	VIII	1.202 E -10	18.080
0	II	2.951E-16	12.470
0	Ш	1.479E-12	16.170
0	IV	2.188E-10	18.340
0	V	2.951E-09	19.470
0	VI	1.122 E-08	20.050
0	VII	3.090E-08	20.490
0	VIII	3.802B-09	19.580
0	IX	1.047E-10	18.020

- Part of the output file using ascd in combination with col.
- This gives the column density and its log value per ion with a significant column density in the model.
- One can thus easily compare the column densities obtained in a slab fit with those in the hot, xabs and warm model.
- Note, not all the ions do have line features in the X-ray band.

Xabs model: output

line	elem	stage	Energy ()V)	Wavelength	Tau0	BW (L-V)	BW (Ann)	Voigt a
1002	~	vπ	(KeV)	(Ang)	4 0 0 1 1	(KeV) 7.6600012.04.0	(Ang) 992779.00	4 0204010 02
1083	š	VII VII	0.57595	1002	60005 4.8311	1.00990E-04 2	0205070-02	4.03240E-03
1001	×	VII VII	0.00333	10.029 0	20102	3.1141312-04 1	075619000	2.1933312-04
1081	Š.	VП	0.09/00	17.706.0	15920	1.01914E-044	1020010-03	3.8801712-04
1080	Š	VП	0.71272	17.000.0	.13200 50300 ³⁰ 00	0.02940E-002	100201-03	1.940000-04
1079	Š	VII VII	0.72084	17.200.8	201001-02	4.91101E-031	2550512-03	1.09200E-04
1078	Š	VП	0.720000	17.000 5	420901012-02	3.123(1E-03) 0.0925579.05 4	.35505E-04	0.009414E-00
1077	Š	VII VII	0.72092	17.009 3	4000112.00	4.000000E-004	-000004E-04	4.3(130E-03
1076	Š.	VП	0.73967	16.930 2	.40901E-04	1.4012912-05 5	.36934E-04	3.203/3E-03
1073	Š	VП	0.73300	10.922 1	139222-02	1.059(4E-05 Z	.44101E-04	2.32138E-03
1079	Š	VII VII	0.73382	10.090 1	24400E-02	(.94-000E-06 I	.04093E-04	1.(30431-03
1073	Š	VП	0.13410	10.010 9	.944251E-03	0.090600-001	.39904E-04	1.337861-03
1073	Š	VII VII	0.73538	10.000 (CO-1470CO	4.5000 / E-00 I	.1024010-04	1.0344£-03
1071	Š	<u>у</u> П	0.13592	10.040 0	.23133E-03	3.84800E-068	. 10533E-05	0.44120E-06
1070	8	VШ	0.73635	10.838 5	.05929E-03	3.111/4E-06 /	.11545E-05	6.844/1E-06
1069	Š	VII VII	0.73671	10.000 4	.15094£-03	4.3000312-00 3	.04019E-05	3.03904E-00 4.2015012.02
1068	Š	VП	0.79705	10.843 3	.46344E-03	2.13332E-064	.009392-05	4.69132E-06
1067	8	VШ	0.73725	10.81/2	.91187E-03	1.79451E-064	.04338E-05	3.95240E-06
1000	Š	<u>у</u> П	0.73746	10.012 2	.47060E-03	1.5233712-06.3	.41290E-05	3.3654012-06
1065	8	VШ	0.73704	10.808 2	.11811E-03	1.3063915-06 2	.97682E-05	2.88242E-06
1064	~	<u>у</u> П	0.13119	16.805 1	.82613E-03	1.120002-002	.300244E-05	4.40490E-UB
1063	8	VШ	0.73793	16.802 1	.58934E-03	9.80819E-07.2	.23321E-05	2.1033315-00
1062	0	<u>уп</u>	0.73804	10.099 1	.39114E-03	8.58/04E-0/ 1	.W0400E-U0	1.009001-00
1061	Š	VШ	0.73814	16.797 1	.22052E-03	7.53527E-071	.71469E-05	1.00210E-00
1060	8	VШ	0.73823	10.795 1	.07744E-03	6.65310E-071	.51357E-05	1.4/310E-06
1028	~	<u>уп</u>	0.73831	10.142 A	.01090E-04	5.9404(12-0)1	.35116E-05	1.31242E-06
1058	8	VШ	0.73838	16.791 8	.57380E-04	5.295/UE-07 1	.2042712-05	1.17068E-06
1057	0	<u>уп</u>	0.73845	10.790 7	.04313E-04	4.15210E-011	.050602-05	1.04/862-06
1056	Š	VШ	0.73851	16.788 6	.92384E-04	4.2//51E-0/9	.7240715-06	9.43943E-07
1055	0	VШ	0.73856	16.787 6	.26348E-04	3.87021E-078	. 1969012-06	8.53264E-07
1054	Š	VШ	0.73860	16.786 5	.65922E-04	3.49680E-077	.94721E-06	7.72988E-07
1055	0	VШ	0.73865	10.785 5	.130952-04	3.1(438E-0) (. 21358E-06	(.03104E-07
1052	Š	VШ	0.73869	16.784-4	.68069E-04	2.8926012-076	.57254E-06	6.40781E-07
1051	0	VШ	0.73872	16.784.4	.27944E-04	2.644/6E-07.6	.00882E-06	5.86018E-07
1050	0	VШ	0.73875	16.783 3	.92220E-04	2.42411E-07 5	.50705E-06	5.36924E-07
1049	Š	VШ	0.73878	16.782.3	.60344E-04	2.22/22E-07 5	.05934E-06	4.93497E-07
1048	0	VШ	0.73881	16.782.3	.31/68E-04	2.05065E-074	.05/91E-06	4.54/94E-07
1047	Š	VШ	0.73884	16.781.3	.0649012-04	1.8944912-074	.30290E-06	4.19867E-07
1046	0	VШ	0.73886	16.781 2	.83413E-04	1.75194E-073	.9/890E-06	3.8///6E-0/
1045	0	VШ	0.73888	16.780 2	.62533E-04	1.6229012-073	.68561E-06	3.59460E-07
1044	0	VШ	0.73890	16.780 2	.43854E-04	1.50743E-07 3	.42322E-06	3.33979E-07
1043	0	VП	0.73892	16.779 2	1.26822E-04	1.40223E-073	.18417E-06	3.10385E-07
1042	0	VШ	0.73893	16.779 2	.11439E-04	1.30713E-07 2	.96808E-06	2.89623E-07
1036	0	VΠ	0.73902	16.777 1	.42774E-04	8.82730E-08-2	.00394E-06	1.95261E-07

- Another possibility with ascd is the option tran.
- In this case all the lines with a certain opacity are listed, here part of the list of O VII.
- Per ion the lines are sorted by opacity.
- The line's energy and wavelength and the EW in keV and Å as well as the Voigt a parameter are listed.

Observational results



- RGS 1st and 2nd order spectra of NGC 5548, the latter is rebinned by a factor of 3 to increase signal to noise ratio.
- Fit is with 3 xabs components for the whole spectrum.

- Continuous photo-ionised absorption model.
- Assume there is absorption between 2 extreme values of the ionization parameter.
- Then one can fit the differential hydrogen column density at these extremes as well as a certain number of points, equidistant in log space, in ionisation parameter.
- Between these points, at Δξ=0.2, the differential hydrogen column density is determined via a cubic spline and a xabs model is calculated.
- Advantage, few parameters to fit a large range in ionisation parameters, however, this also means that the abundance, velocities and covering factor parameters are tied.
- Possible to use multiple warm components, if for instance different velocity components.

• Special parameters:

Extremes of ionization parameter: xil1 and xiln, have to be set by hand.

Number of points where the differential hydrogen column density is fitted, thus minimum is 2 and maximum 19, this number cannot be determined in a fit.

The logarithmic spacing of $\Delta\xi$ for which the absorption spectrum is calculated, ranges between 0.1 and 1, this parameter has to be set by hand.

The differential hydrogen column density at the ionisation extremes as well as the number of points in between.



Absorption for warm model between log ξ =-1 and 3 with dN/d ln ξ for both equal to 10^{24} m⁻².

- Black model same as before, red curve assuming that the highest ionization point has dN/d lnξ=10²² m⁻².
- So there is less short wavelength absorption.







Black same model as previous ones, red: having 5 points withchanging $dN/d \ln \xi$ between 10^{23} and 10^{28} m⁻² (low to high ionization).

Difference between models for $\Delta \xi = 0.2$ (black) and 1 thus a coarser grid which calculates the transmission (red).

Warm model: output

п	ion		log Xi	$\log T$	log column
			(1E-9 Wm)	(keV)	(m**-2)
1	н	I	0.41	-2.74	20.56
2	H	II	2.49	-1.62	25.42
3	He	I	-0.54	-2.81	18.57
4	He	II	0.49	-2.73	21.74
5	He	IΠ	2.49	-1.62	24.35
21	С	I	-0.76	-2.82	14.44
22	С	II	-0.64	-2.82	17.86
23	С	Ш	-0.38	-2.80	19.46
24	С	IV	0.15	-2.74	19.87
25	С	V	1.05	-2.58	20.69
26	С	VI	1.94	-2.09	20.95
27	С	VII	2.58	-1.54	21.69
28	Ν	I	-0.76	-2.82	13.96
29	Ν	II	-0.62	-2.81	17.26
30	N	ΙП	-0.36	-2.79	19.08
31	Ν	IV	0.07	-2.75	19.55
32	N	V	0.64	-2.67	19.69
33	N	VI	1.45	-2.41	20.36
34	Ν	VII	2.14	-1.93	20.62
35	Ν	VIII	2.62	-1.50	21.17
36	0	I	-0.80	-2.83	14.67
37	0	II	-0.67	-2.82	17.85
38	0	Ш	-0.39	-2.79	19.69
39	0	IV	0.03	-2.75	20.36
40	0	V	0.53	-2.69	20.48
41	0	VI	1.06	-2.57	20.59
42	0	VII	1.73	-2.24	21.25
43	0	VIII	2.28	-1.81	21.47
44	0	IX	2.67	-1.46	21.85

- Specifically for the warm model, ascd has the option warm.
- This lists per ion logξ and log T in keV and the column density of the ion. Thus again one can easily compare the warm results with those obtained from slab or xabs.
- The other options, such as col and tran also work for the warm model.



Effect of assuming that the lines are formed by a blend of different velocity components (red). Difference between a model with solar abundances, and one in which iron has an abundance of a 3rd solar.



- The absorption spectrum can be calculated per element (up to Zinc).
- dN/d lnξ=10²⁵ m⁻² at all the points and for all the curves.

Comparison between warm and xabs



- Comparison between 2 xabs models and the warm model. Note the difference in ionization parameters.
- There is more low ionization absorption in the warm model, hence more continuum absorption, and some extra lines.

Observational results



Results for Mrk 279
(Costantini et al.
2007) using slab
model for some
elements: individual
symbols and warm,
the solid line.

Observational results



- Model transmission for all 7 absorption components and the resultant combination, using hot for Galactic absorption and absorption in the IC 4329A galaxy (component 2).
- Local O VII is modelled as a delta line, as it is the only line detected, and only weakly so.
- The other components are absorption close to the BH and are modelled by xabs.