Atomic data needs for high resolution X-ray astronomy

Adam Foster
Smithsonian Astrophysical Observatory
Definitions

“High Resolution”
\[ \Delta E = 5 \text{eV} \]
\[ \frac{E}{\Delta E} \approx 1000.0 \]

X-ray
\[ 0.3 < E < 50 \text{ (keV)} \]
(no molecules)

H-like, He-like and L-shell
Upcoming Missions: Astro-H (2016)

- Hard X-ray Imaging System (HXI)
- Soft X-ray Spectroscopy System (SXS)
- Soft X-ray Imaging System (SXI)
- Soft Gamma-ray Detector (SGD)

Observe energies from 0.3-300keV
Athena - launch 2028

European Space Agency “L2” mission

2.5eV energy resolution

High spatial resolution (~5 arcsec)

Exploring “The Hot and Energetic Universe”

➢ the formation and evolution of groups and clusters of galaxies
➢ the chemical evolution of hot baryons
➢ feedback effects of active galactic nuclei in clusters
➢ missing baryons thought to populate the intergalactic medium
➢ formation and early growth of black holes
➢ accretion by supermassive black holes through cosmic time
➢ galaxy-scale feedback involving active galactic nuclei and star formation
➢ physics of accretion onto supermassive black holes as a driver of active galactic nuclei

Not going to say more as we have 13+ years to wait...
Lineshapes

➢ SXS: 5eV resolution, non-dispersive spectrometer
➢ Allows study of extended objects with high resolution for the first time
➢ Astro-H goal: “Revealing the large-scale structure of the Universe and its evolution”
➢ Galaxy clusters are of particular interest

Need accurate line shapes for modeling these features
Line widths measured by current calorimeters are dominated by the natural line widths – which are not known for many useful elements!
Absorption Cross Sections

Chandra HETG observations of interstellar medium absorption.

Initially find poor fit, low ionization parameter

Shift wavelengths of O I and O II cross sections, get better fit

Absorption cross section wavelengths known to \( \sim 50\text{mA} \) accuracy. Current detectors can already get to \( \sim 23\text{mA} \).
Non-equilibrium

Have "complete" data for all ions of all elements. Very few calculations/measurements to compare with, especially for inner shell ionization. Doubly so for K\(\beta\)
Non-equilibrium

### Quantity

<table>
<thead>
<tr>
<th></th>
<th>Ozawa</th>
<th>AtomDB 3.0</th>
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<tbody>
<tr>
<td>kTe</td>
<td>1.5keV</td>
<td>1.5keV</td>
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<tr>
<td>Fe_abund</td>
<td>4.44</td>
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<td>Ni_abund</td>
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<td>3.63</td>
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<tr>
<td>norm</td>
<td>0.16</td>
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</table>
DR-Lines

DR satellite lines are a strong potential temperature diagnostic

Satellite line emissivities need to be updated and expanded
**3.55keV “sterile neutrino” Line**

Stacked 73 galaxy clusters at their rest frame.

“Smears out” instrumental effects

Find residual line at 3.57keV in a range of cluster samples.

Found in all instrum

Nearby atomic lines:
- K XVIII 2p-1s @ 3.515keV
- Ar XVII DR @ 3.62keV
(Low Energy!) Charge Exchange

Simplified CX model created to model SWCX. Improved model (REAL cross sections!) needed to model comets/planetary atmospheres.

Ongoing project with University of Georgia to obtain theoretical cross sections

Fx(30-124Å) = 2.5x10^-8 cgs/sr
LHB (1.06±0.1 MK, 25% Fx)
SWCXlo (0.9±0.1 MK, 25% Fx)
SWCXhi (2.3±0.1 MK, 50% Fx)
SWCX abunds (Von Steiger+00)
LHB abunds from Warm clouds (Savage & Sembach06)

Model's strong CHIPS lines:
(systematics ~ 6 LU)
O VI (173Å) ~ 11.7 LU
O VI (150Å) ~ 10.4 LU
Fe IX(171Å) ~ 6.1LU

X-ray lines:
CV(41Å) ~ 8.5 LU
C VI(33.7Å) ~8.5 LU
O VII(22.1Å) ~8.3 LU
O VIII Lyα ~2.5 LU

Surface Brightness (counts/s/sr)
Wavelength (Å)
Comparison of Models

Strongest 100 lines in a 2keV plasma

Need to identify how and why these models differ!
Uncertainties!

Need to identify how and why these models differ!
We are about to have much improved spatial and spectral resolution, but not all requirements are driven by this. Identified needs are:

- Line widths & shapes
- Absorption Cross Sections (energy level accuracy)
- Inner shell ionization collision strengths
- Dielectronic Recombination Satellite Lines
- Charge Exchange cross sections
- Model Comparison
- Uncertainties