Fe Atomic Data for NEI Plasmas

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Image Credit: NASA/CXC/Rutgers/K. Eriksen+

Tycho’s SNR

Kristoffer Eriksen (LANL)

CfA AtomDB Workshop 8/9/2012
Iron in Tycho’s SNR

SN 1572, normal SN Ia (Badenes+ 2006, Krause+ 2008)

over half of ejecta mass thought to be $^{56}\text{Ni}$ (now $^{56}\text{Fe}$)

$\text{Si K}$

$\text{Fe L}$

$\text{Fe K}$

$\text{Chandra LP} \sim 750 \text{ ks}$

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Iron in Tycho’s SNR

SN 1572, normal SN Ia (Badenes+ 2006, Krause+ 2008)

over half of ejecta mass thought to be $^{56}\text{Ni}$ (now $^{56}\text{Fe}$)

$E = 6.528$ keV

$\text{Fe XVII-XXI}$

$\text{Chandra LP} \sim 750$ ks

Kristoffer Eriksen (LANL)
## new FAC Calculations, Fe XVII-XXVI

<table>
<thead>
<tr>
<th>ion</th>
<th>AtomDB v2</th>
<th>new FAC</th>
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<tbody>
<tr>
<td></td>
<td>K - n</td>
<td>L - n</td>
</tr>
<tr>
<td>Fe XVII</td>
<td>n/a</td>
<td>7</td>
</tr>
<tr>
<td>Fe XVIII</td>
<td>n/a</td>
<td>5</td>
</tr>
<tr>
<td>Fe XIX</td>
<td>n/a</td>
<td>5</td>
</tr>
<tr>
<td>Fe XX</td>
<td>n/a</td>
<td>5</td>
</tr>
<tr>
<td>Fe XXI</td>
<td>n/a</td>
<td>5</td>
</tr>
<tr>
<td>Fe XXII</td>
<td>n/a</td>
<td>6</td>
</tr>
<tr>
<td>Fe XXIII</td>
<td>n/a</td>
<td>7</td>
</tr>
<tr>
<td>Fe XXIV</td>
<td>n/a</td>
<td>7</td>
</tr>
<tr>
<td>Fe XXV</td>
<td>10</td>
<td>n/a</td>
</tr>
<tr>
<td>Fe XXVI</td>
<td>10</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Agreement at Fe K

Fe Kα $kT_e = 4.5$ keV, Electron Impact Excitation only
Tycho Fe knot - XSPEC model

$N_H = 6.7 \times 10^{21}$ cm$^{-2}$

$kT_e (\text{Fe}) = 5.63$ keV

$n_e t(\text{Fe}) = 1.78 \times 10^{10}$ cm$^{-3}$ s

$\chi^2 = 1.7$
Tycho Fe knot - new Fe model

$N_H = 6.5 \times 10^{21}$ cm$^{-2}$

$kT_e (\text{Fe}) = 5.33$ keV

$n_e t(\text{Fe}) = 1.63 \times 10^{10}$ cm$^{-3}$ s

$\chi^2 = 0.91$
What About Resonances?

- Resonance structure affects the L-shell collision strengths near threshold.
- For high-$T_e$ NEI plasmas, we’re way beyond threshold.
- Weak lines most affected -- at CCD resolution feel less effect.
- Probably not true for low-$T_e$ photoionized plasma.

Fe XVIII, excitations from ground

- $2s^1 2p^6 \, ^2 S_{1/2}$, $E_{th} = 133.78$ eV
- $2p^4 \, 3d^1 \, ^2 D_{5/2}$, $E_{th} = 872.62$ eV
- $2p^4 \, 4d^1 \, ^2 D_{5/2}$, $E_{th} = 1084.40$ eV

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A near-threshold, CIE case: E0519

SNR 0519-69.0, Fe-rich ejecta

Fe L

Si K

S K

$N_H = 2.0 \times 10^{21} \text{ cm}^{-2}$

$kT_e = 0.99 \text{ keV}$

$\chi^2 = 0.66$

Energy (keV)

counts s$^{-1}$ keV$^{-1}$
A near-threshold, CIE case: E0519

- Replaced FAC data with R-matrix data, where available
- $< 3\%$ difference in $T_e$, $5\%$ in norm.
- far less than statistical errors
A near-threshold, CIE case: E0519

- Replaced FAC data with R-matrix data, where available
- < 3% difference in $T_e$, 5% in norm.
- Far less than statistical errors

Take away point:
For CCD resolution data, adding more levels more important than superior accuracy atomic data
Why Stop at Ne-like?

Fe logTe: 7.76 (5.80e+07 K, 5.00 keV)

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Outside the Tycho Fe knot

Chandra LP $\sim 750$ ks
Outside the Tycho Fe knot

Fe K: 6.44 keV
low ionization!

resid. at 730 eV:
\[ 2l^7 \cdot 3l^{p+1} \rightarrow 2l^8 \cdot 3l^p \]
3rd row L-shell ionization?
Same 730 eV residual

RCW 86 (Yamaguchi+ 2011)
New FAC Calculations

<table>
<thead>
<tr>
<th>ion</th>
<th>$n_{max}$</th>
<th>levels</th>
<th>spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe XX</td>
<td>8</td>
<td>4073</td>
<td>converged, for comparison</td>
</tr>
<tr>
<td>Fe XVI</td>
<td>5</td>
<td>7101</td>
<td>maybe converged?</td>
</tr>
<tr>
<td>Fe XV</td>
<td>3</td>
<td>1463</td>
<td>not converged</td>
</tr>
<tr>
<td>Fe XIV</td>
<td>3</td>
<td>4936</td>
<td>not converged</td>
</tr>
</tbody>
</table>

unwieldy for FAC, LANL codes work in progress
Low Ionization Fe: E0509-67.5

very much work in progress

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Summary

• New Fe XVII-XXVI data ready, paper coming soon.

• Major improvement over what’s currently available, due to much larger structures

• Will be incorporated into AtomDB soon.

• Some young SNRs show evidence for lower Fe ion states

• much more challenging atomic physics problem: can guarantee that what’s in XSPEC now is not very good.

• be very cautious of low $n_{et}$, know your charge states!

• minor Fe-peak elements (Cr, Mn, Co, Ni) calculations complete as well