Astrophysical charge exchange

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SPEX: collisional, photoionized, charge exchange plasma

https://www.sron.nl/astrophysics-spex
Charge exchange in a nutshell

- atom-ion collision
- fall onto a highly excited level
- cascade to the ground state by emitting photon

- new CX code (n,l,v-resolved) in SPEX by Gu+2016, incorporating latest cross section calculations (kronos, Mullen+2017)

- Both single-v and Maxwellian options
Charge exchange astrophysics

• First introduced in comets (Lisse+1996)

• Solar wind CX in heliosphere and planets (Dennerl+2006, Branduardi-Raymont+2007, Smith+2014)

• Supernova remnants (Katsuda+2011, Cumbee+2014), starburst galaxies (Tsuru+2007, Cumbee+2016).

• Clusters of galaxies (Fabian+2011, Walker+2015)
X-ray comets: 3-D diagnostic of solar winds

optical image on X-ray background
Dennerl et al. 2003

RGS spectrum (Gu et al. 2016, Mullen et al. 2017)
SNR in our Galaxy: CX or ionized absorption

North polar spur (Gu+2016)

- Spectrum best described by ionized absorption with column density/temperature well matching the Galactic halo model. NPS is in the halo!
- Solve the ‘too high N-to-O abundance’ problem (Miller+2008).
AGN wind CX lurking in UV

NGC 1275 (Gu+2017)

- Offset velocity $\sim 3000$ km/s
- agree with $\text{Ly}\alpha$ absorbers
- AGN outflow
3.5 keV line from galaxy clusters

- Bulbul+2014 and Boyarsky+2014 claim a 3.5 keV line in stacked cluster spectra, not associated with any known atomic line.

- Interpreted as possible decay of dark matter candidate (so-called sterile neutrino)

- > 300 citations, most of them are pure particle science discussing possible decay model.

- Controversial: instrumental effects, a few claims of detection and many non-detection afterwards, including a negative result with 1.6 Ms XMM data of a dwarf galaxy.
Possible atomic origin

- Charge exchange of fully ionized sulfur with hydrogen atom produces a line at nearly 3.5 keV
- Clusters have sufficient ingredients for charge exchange at 3.5 keV.
- Hitomi data supports.

Gu+2015
CX better explains 3.5 keV dilemma

<table>
<thead>
<tr>
<th></th>
<th>Cold gas?</th>
<th>3.5 keV?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perseus cluster</td>
<td>Massive $&gt; 10^{10} M_{\text{sun}}$</td>
<td>Yes</td>
</tr>
<tr>
<td>Virgo cluster (M87)</td>
<td>Little $\sim 10^6 M_{\text{sun}}$</td>
<td>No</td>
</tr>
<tr>
<td>Coma cluster</td>
<td>Little</td>
<td>No</td>
</tr>
<tr>
<td>Ophiuchus cluster</td>
<td>Little</td>
<td>No?</td>
</tr>
<tr>
<td>M31</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Galactic center</td>
<td>Yes</td>
<td>Yes?</td>
</tr>
<tr>
<td>Dwarf galaxies</td>
<td>No</td>
<td>No (1.6 Ms)</td>
</tr>
</tbody>
</table>
New supports: O8+ CX with H

- 2.8σ feature at O VIII Lyδ
- Cannot be iron lines
- Cannot be astrophysical effects
- in line with the sulfur model for 3.5 keV
Affecting O abundance

- O abundance of hot ICM (mostly measured by O VIII Lyα) might be overestimated by 8 – 22% (for $v = 100 − 800$ km/s).
- Accurate abundance measurement is a key science.
- Hitomi data shows Fe might be overestimated by 5 – 10% for CX.
- CX line intensity $\sim N_{z+1} v q_{z+1}$, thermal line intensity $\sim N_z R_{exc}$ — different z-scaling.
- Cross section from Janev+1993, update needed.
Conclusion

• CX is commonly regarded only as a systematics in astrophysics

• Can be a potentially important systematics for chemical composition of clusters (hence star forming history)

• High resolution UV/X-ray spectroscopy needed to make CX a serious topic:
  ➢ 3-D solar winds
  ➢ AGN winds/feedback
  ➢ Formation of Ha filaments in clusters

• What’s next: WHIM accretion? CX white paper for XARM/Athena?

• Accurate cross section calculation and lab data support from H- to Ne- like.