The Science team at MIT:
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Distribution of Matter in Galaxies

Context: *High Resolution X-ray Absorption Spectroscopy*

Elements: C, O, Ne, Mg, Si, S, Ar, Ca, Fe, Ni

Molecules: CO₂, CO, O₂, H₂O…., C₅H₆O, CH₂O₂,…….

Dust: Structure & Depletion

Neutral Abundances
Ionized Abundances
Star Formation Rates
Missing matter (WHIM)

HEAD meeting, Chicago, June 28-30, 2015
EINSTEIN (1878 – 1982):
Detection of O K edge substructure: 1s-2p resonance in Crab (Schattenburg & Canizares 1986) with the SPC

ROSAT (1990 – 1999):
First All-Sky X-ray Survey 1990-1992
Range: 0.2 – 2.4 keV
Resolution: 2 – 5
Sensitivity $> 10^{-16}$ erg s$^{-1}$ cm$^{-2}$
Catalog: $\sim 10^5$ X-ray sources

Medium resolution spectra of SNRs & Galactic Center
Range 0.5 – 8 keV
Resolution: 5 - 60

CHANDRA & XMM-Newton (1999 - ...):
Bright Galactic X-ray sources
Range: 0.2 – 8 keV (1.5 keV RGS)
Resolution: 200 - 1200
Near Future:

CHANDRA & XMM-Newton
(1999 - ...)

eROSITA (2017 - ...):
First 0.5 – 10 keV All-Sky survey
Resolution: 5 – 60
Sensitivity: < 10^{-17} erg s^{-1} cm^{-2}
Catalog: ~ 10^5 X-ray sources

ASTRO-H (2016 - ...):
First Micro-calorimeter
Extended source spectroscopy
Range: 0.2 – 10 keV
Resolution: 4.6 eV
44 (0.2 keV)
250 (1.0 keV)
1400 (6.4 keV)
Q: What do we learn from Photoelectric and Warm X-Ray Absorption:

- State and Consistency of Atomic and Molecular Matter
- Absolute Matter Abundances: Neutral, Ionized Matter
- Cold, Warm, Hot Properties: Density, Temps, Kinematics
- Solid State Properties of Matter, Dust
- Accurate Redshifts up to $z = 4$
- No other waveband can offer all these simultaneously
Distribution of Matter in Galaxies

Fe L edges, Mg, Si, S edges: dust

Cold, Warm, and Hot phases of ISMs: C, N, O, and Ne – K edges

HEAD meeting, Chicago, June 28-30, 2015
Fe L edges, Mg, Si, S edges: dust

Cold phases of ISMs: atomic Si, Silicates, Si XIII
Distribution of Matter in Galaxies

NGC 3783,
Kaspi et al. 2002

AGN

HEAD meeting, Chicago, June 28-30, 2015
Map X-ray sources in Local group Galaxies

Diagnose X-ray emissions From galactic halos:

Kinematics and matter properties of starburst galaxies

Kinematics and matter properties of X-ray

HEAD meeting, Chicago, June 28-30, 2015
Distribution of Matter in Galaxies

WHIM: baryonic matter absorption

HEAD meeting, Chicago, June 28-30, 2015
Q: What instrumentation do we need to realize effective X-ray absorption studies:

→ high efficiency X-ray optics (segmented) with optical performance $< 0.1'' - 5''$

→ high resolution X-ray gratings with $R > 3000$ for $E < 1.5$ keV

→ X-ray micro-calorimeters with $R > 2000$ for $E > 1.5$ keV

→ Need $R > 10000$ to resolve thermal line properties
Q: What can we do in the coming years/decades:

→ Within the next 2 – 5 years we might utilize sub-orbital rockets to pursue specific science goals in the above categories and obtain sufficient technology readiness but should have at least some small explorer opportunities (i.e. Micro-X type)

→ Within the next 5 - 10 years medium explorer mission opportunities should be realized to pursue some limited surveys

→ Beyond 10 years we should be able to perform proper and deep surveys with the power of a Generation-X-type X-ray observatory
Distribution of Matter in Galaxies

~5000 Galactic Sources:
Log $f_x = [-9, -13]$
<exposure> > 10 ks

~ $10^{2.2}$ Nearby Galaxies/AGN:
Log $f_x > -13$
<exposure> > 30 ks

> $10^3$ Deep Survey Sources:
Log $f_x = [-10, -14]$
<exposure> > 100 ks
## Distribution of Matter in Galaxies

### ~5000 Galactic Sources:

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<tbody>
<tr>
<td>$[-9, -13]$</td>
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Effective Galactic Survey:

- 210 X-ray sources  < 43 ks  →  9.1 Ms
- Line Detection, Abundance, Line Profiles, Kinematics

### ~ $10^{2.2}$ Nearby Galaxies/AGN:

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<td>$&gt;-14$</td>
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Nearby Galaxy Survey:

- 66 Exposures  < 51.5 ks  →  3.4 Ms
- Line Detection, Abundance, Line Profiles, Kinematics

### $10^3$ Deep Survey Sources:

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Deep Surveys:

- 30 X-ray Sources  < 167 ks  →  5.0 Ms
- Line Detection, Abundance, Line Profiles, Kinematics

### 30 Ms in 3 yrs @ 306 targets

→ 17.5 Ms
Distribution of Matter in Galaxies

→ ARCUS Explorer Proposal (PI: Randall Smith 2015):

Baseline Effective Area (@1 keV) 0.7 m²
Angular Resolution 1.5” HPD
Energy Resolution (@0.5 keV) E/dE=>2770 (average) 1550
Energy Range 0.24 – 1.40 keV
Field of View 10.5’ x 10.5’
Time Resolution 1 s
Observing Efficiency 55%
Calibration ---
Launch Vehicle Space-X Dragon
Deployment ISS
Launch Date 2020+
AEGIS Mission Concept (MKI/Mark Bautz 2011):
(An Astrophysics Experiment for Grating and Imaging Spectroscopy)

Baseline Effective Area (@1 keV) 1 m²
Angular Resolution < 5-10” HPD
Energy Resolution (@0.5 keV) E/dE > 3000
Energy Range 0.3 – 1.0 keV
Field of View 19’ x 19’
Time Resolution 3 s
Observing Efficiency 85%
Calibration ---
Launch Vehicle Falcon-9
Orbit L2
Launch Date 2020+
X-Ray Surveyor Concept (Weisskopf et al. 2015, SPIE):

Baseline Effective Area (@1 keV) 4 m²
Angular Resolution 0.33" HPD
Energy Resolution (@1 keV) E/dE => 5000
Background (< 2.0 keV) 0.004 cts/ks/arcsec²
Energy Range 0.2 - 10 keV
Field of View ~ 15’ x 15’
Time Resolution 50 ms
Sky Availability 90%
Calibration 3% absolute
Launch Date 2027+

See Poster by R. Heilmann et al. for CAT grating developments and design
Concluding Remark:

X-ray absorption spectroscopy is a powerful tool to study existing forms of matter in our Universe. The roadmap for the next 15 years needs to lead to means and strategies which allows us to perform such absorption surveys as effectively as surveys are now or in very near future quite common in astronomy pursued in other wavelength bands such as optical, IR, and sub-mm.