X-ray Sources in Nearby Galaxies

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Why X-rays?

• Energetic
  - Heating and evaporating (dust, stars, etc.).

• Penetrating
  - Seeing through materials up to \( N \sim 10^{24} \text{ cm}^{-2} \).

• Produced by high-energy processes
  - Interesting in their own right
  - Shaping the formation and evolution of galaxies
X-ray observations: Chandra and XMM-Newton

- Spatial resolution up to ~ 1"
- Spectral resolution up to 400 km/s
- Energy coverage 0.3-10 keV (broad band)
  - 0.3-2 keV (Soft)
  - 2-10 keV (hard)
Diversity of X-ray sources

• Discrete sources
  - AGNs, LMXBs, HMXBs: bright and essential to the study of accretion physics.
  - SNe, SNRs, YSOs, CVs, ABs, etc.: Typically faint, numerous, and unresolved even in nearby galaxies.
  - Populations are sensitive to SFR and stellar mass/dynamics.

• Diffuse emission
  - Tracing hot plasma heated by stellar and/or AGN feedback.
  - Sensitive to galactic environment (e.g., SFR, cool gas, and galaxy gravity).
AGNs Are Powerful!

- Luminosity: $L_x > 10^{42}$ erg/s.
- Typical spectrum: power law with photon index $\Gamma \sim 2$.
- Intimately related to galactic nuclear SF.
- Radiation and Mechanical energy releases can greatly influence how galaxies form and evolve (e.g., the mass relationship between galactic bulges and SMBHs).
Examples of AGN feedback effects on hot plasma in elliptical galaxies

Credit: NASA/CXC/UFRGS/R.Nemmen et al.
AGNs could be hidden!

- Many AGNs are obscured (e.g., Type 2 Seyferts), even Compton thick.
- Reflected/reprocessed light (e.g., 6.4 keV florescent line and mid-IR enhancement) can still be observed.
- Also AGNs come and go, leaving relics that could last for a long time.

Even Low-$L_x$ AGNs ($L_x < 10^{42}$ erg/s) can be significant energy sources!

- Local group galaxies contain only such AGNs
- Undergoing radiatively inefficient accretion
- Sgr A* and M31* show flares/bursts
- Mechanical outputs may still be significant in shaping galactic nuclear environment

Baganoff et al. (2003)
HMXB

- Spectrum: power law with $\Gamma \sim 1.2$ and a cutoff at $\sim 20$ keV, plus Fe emission line ($6.4-6.7$ keV) with EW=0.2-0.6 keV
- Luminosity function:
  \[ \frac{dN}{dL_x} \propto SFR(M_\odot/\text{yr}) L_x^{-\alpha} \]
- \( L_{x,t} = (6.7 \times 10^{39} \text{ erg/s}) SFR(M_\odot/\text{yr}) \)

LMXB

- Spectrum: power law with $\Gamma \sim 1.7$ (Irwin et al. 2003)
- \( L_{x,t} = (8.0 \times 10^{39} \text{ erg/s}) \) per \( 10^{11} M_\odot \).

Gilfanov 2004; Kim & Fabbiano 2004
X-ray binary pop is sensitive to the stellar dynamics: M31 bulge

With 1’ radius:
• Enhanced number of sources with $L_x > 10^{36}$ erg/s $\rightarrow$ dynamic formation of LMXBs
• But deficit in $10^{36} > L_x > 10^{35} \rightarrow$ destruction of binaries

Radial source number density distribution

Voss & Gilfanov 2007
Fainter X-ray sources: CVs and ABs

- CVs typically with hard spectra and $5 \times 10^{31} < L_x < 10^{34}$ erg s$^{-1}$, whereas ABs with soft spectra and lower $L_x$.
- Their combined contribution is $4 \times 10^{27}$ erg s$^{-1}$ $M_\odot^{-1}$ in the field (Sazonov et al 06), but is sensitive to the dynamics in globular clusters.

LF slope vs. star encounter rate of GCs

Xu & Wang (2011) in prep
Diffuse soft X-ray emission: M31

Li & Wang, 2007
Diffuse hot gas outflow driven by Ia SNe

Li & Wang 2007

IRAC 8 micro
K-band
0.5-2 keV

T ~ 3 x 10^6 K
Lx~2x10^{38} erg/s, only ~1% of the Type Ia SN energy input.
No massive star formation within the bulge.

Injection of Ia SN (4x10^{-4}/yr), and stellar mass loss follows the stellar light.
The injection drives a bulge outflow and also reduces the accretion to the SMBH.

Tang, Wang, MacLow, & Joung 2009
Strong deviation of the OVII Ka triplet from the thermal plasma model: the forbidden line at 21.80 Å is much stronger than the resonance line at 21.60 Å.

Liu, Wang, Li, & Peterson 2010
The most likely cause of the high f/r ratio is the charge exchange, which has a cross-section of $\sim 10^{-15}$ cm$^{-2}$. 

Porquet & Dubau (2000)

Peter Beiersdorfer
Hydro-simulation of SNRs, bulge outflow, nuclear disk, and SMBH accretion

- A cool gas inflow is assumed to continuously feed the nuclear disk around the SMBH.
- The disk is being destructed/evaporated increasing the interface between hot and cool gas, enhancing the CX and mass loading to the hot gas.
Charge exchange in starburst galaxies

Composite of optical (HST), infrared (Spitzer), and X-ray (Chandra) images

M82

Liu, Mao, Wang 2011
ACIS Images of M83 and M51 plus RGS spectra of the OVII Ka Triplet

Soria & Wu (2002)
Antennae galaxy

Optical (Yellow), X-ray (Blue), Infrared (Red)
CX may also be important in many other circumstances

(Lallement 2004)

NGC 4438 in the Virgo Cluster

Ha+[NII] image (Kenney et al. 1995).

Chandra 0.3-2 keV image, Machacek et al. 2004
Diffuse hot plasma shaping the ISM

Diffuse hot plasma: disk/halo interaction

- Scale height $\sim 2$ kpc + more distant blubs.
- $L_x$(diffuse) $\sim 4 \times 10^{39}$ erg/s

Red – H$\alpha$
Green – Optical R-band
Blue – 0.3-1.5 keV

NGC 5775

Li et al. 2008
Li et al. 2007

Average T \sim 6 \times 10^6 \text{ K}

L_x \sim 4 \times 10^{39} \text{ erg/s}, \sim 2\% \text{ of Type Ia SN energy}

Not much cool gas to hide/convert the SN energy

Mass and metals are also missing!
- Mass input rate of evolved stars
  \sim 1.3 \ M_{\odot}/\text{yr}
- Each Type Ia SN \rightarrow 0.7 \ M_{\odot} \text{ Fe}
Extraplanar diffuse $L_x$ vs. galaxy properties

Based on Chandra observations of 53 edge-on galaxies with $D < 30$ Mpc, $exp > 10$ ks, $incl > 60^\circ$, $1'<D_{25}<16'$. 

Diffuse X-ray (0.3-1.5 keV) emission efficiency:

$$L_x(10^{30} \text{ erg/s})/\text{SFR}(M_\odot \text{ yr}^{-1}) = 14M_{TF}^{0.72}M_*^{-0.56}$$

Li & Wang (2011) in prep
Topics not covered

- Feeding of AGNs
- Evolution of HMXBs and LMXBs (talk by Andreas Zezas).
- Discrete source populations such as SNe, SNRs, YSOs.
- Effects of AGN energy injection, accretion from the IGM, clustering environment on diffuse hot plasma.
- Diffuse hard X-rays: e.g., reflection, inverse Compton scattering, & synchrotron radiation (e.g., Brian Lacki’s talk on Thursday), which may be important in starbursts and AGN relics.
Summary: discrete sources

• AGNs:
  - Brightest X-ray sources
  - Strong feedback → affecting galactic or circumnuclear environments

• Stellar objects
  - HMXB and LMXB populations are well correlated with SFR and stellar mass.
  - This + observed $L_X$ can be used to constrain the presence of AGNs in distant galaxies.
  - The populations of LMXBs, CVs, and ABs are sensitive to the dynamic effects of stellar clusters or even galactic inner bulges.
Summary:
Diffuse Soft X-ray emission

• Traces stellar feedback
  – Disk - driven by massive star formation
  – Bulge - heated primarily by Type-Ia SNe
• Typically, $L_x < \text{a few } \% \text{ of the feedback energy} \rightarrow \text{outflows from stellar spheroids, as well as starburst galaxies}$
• A substantial fraction of the diffuse soft X-ray emission may arise from the charge exchange.
Operating X-ray Telescopes

- XMM-Newton
- Chandra
- Suzaku
- SWIFT
Future X-ray telescopes

NuSTAR

eROSITA 2012

GEMS

Gravity and Extreme Magnetism SMEX

Athena???

Astro-H, planned for launch in 2013