Cosmic Star Formation History and Chandra Deep Field Surveys

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Plan

• Evolution of X-ray luminosity
• Role of cosmic star formation history
• Status of understanding
• logN-logS plots: X-ray diagnostics
• Normal/Starburst galaxies vs. AGN
• Correlations between X-rays & other wavebands: Optical, IR, Submm, Radio
Evolution of $L_x$ & $L_x/L_B$

$L_x/L_B$ rises by $\sim 10$ from $z=0$ to $z \sim 1$, falls for $z = 3 \rightarrow 4$

Lehmer et al. 2005
$L_x$ Evolution: Star Formation History

Ghosh & White 2001
$L_x$ Evolution: Detail

![Graph showing $L_x$ evolution with Gaussian distribution.](image)
**L_x Evolution: Understanding**

**Theory:**
- L_x rises by ~10 as z=0→1 for typical LMXB lifetimes:
  - \( \tau_{PSNB} \sim 2 \text{ Gyr} \)
  - \( \tau_{LMXB} \sim 1 \text{ Gyr} \)
- L_x/L_B rises by ~10 only if L_B has little evolution

**Observation:**
- L_x/L_B rises by ~10 as z=0→1
- But L_x rises by ~3 ?
  - Brandt et al. 2001
  - Hornschemeier et al. 2002
- Then L_B falls by ~3 as L_x rises ??
L_x Evolution: Understanding

\[
\log(L_x/L_B) = \log L_x - 2.5 \log L_B
\]

Lehmer et al. 2005

How to understand rise of L_x by \(\sim 3\) in z=0→1?
L_x Evolution: Understanding

- LMXB evolution slower?
  \[ \tau_{\text{LMXB}} \approx 2 \text{ Gyr} \]
- Bandpass change factor not right due to soft excess?
  \[ L_x = 4\pi d_L^2 f_x (1+z)^\Gamma^{-2} \]
  \( \Gamma = 2 \) normally used \( \text{Kim et al. `92, Ptak etal. `99} \)
- But... LMXB spectra have soft excess?
LMXB Spectrum: Soft Excess

Extrapolation of 2-10 keV power law to soft band may underestimate flux

Sidoli et al. 2005
Normal/Starburst Galaxies vs. AGN

**Discriminators**

- X-ray luminosity: Critical value $\sim 3 \times 10^{42}$ erg s$^{-1}$, AGNs more, galaxies less
- X-ray spectra: Critical hardness ratio $\sim 0.8$, AGNs harder, galaxies softer
- $f_x/f_{opt}$ ratio: Critical value $\sim 0.1$, AGNs more, galaxies less
- Optical spectroscopy: Broad/Hi-ionization AGN emission lines
- Radio properties
logN-logS Diagnostics

• Bulk (85-95%) of X-ray background power from AGNs

• Only ~5-15% from galaxies:
  - Starbursts dominate in soft
  - Quiescents dominate in hard

• But in number density, star-forming galaxies will overtake AGNs at soft flux ~ $10^{-17}$ erg cm$^{-2}$ s$^{-1}$
Summary

• Lx evolution qualitatively correct, details to be clarified:
  - Observational issues
  - More detailed theory

• XRB power dominated by AGNs, but number counts dominated by normal/starburst galaxies at faint fluxes

• X-ray correlations with other wavebands indicate diagnostic value of X-rays in probing star formation
logN-logS Diagnostics

Soft Band
0.5-2 keV

Total Counts: Slope
~ 0.55

XRB Resolved Fraction
~ 89% soft

Galaxies: Slope
Total & Quiescent ~ 1.3
Starburst ~ 1.7
Elliptical ~ 1.1

Bauer et al. 2004
Normal/Starburst Galaxies vs. AGN

Bauer et al. 2004
X-ray/Optical Correlations

**Optically Bright X-ray Faint (OBXF) galaxies**

- OBXF: $\log(f_x/f_R) \sim -2$ or less
- “Distant analogs of `normal’ galaxies in the local universe.” Hornschemeier et al. 2003  $z \sim 0.1 \rightarrow 0.8$
- OBXF dominated by non-AGN: quiescent and starburst galaxies, some low-luminosity AGN
- $L_x > \text{“normal” galaxies, soft X-ray spectra}$
- OBXF logN-logS slope $\sim 1.7$ very steep, as for starbursts: will dominate at low $S$
- Several off-nuclear ULXs
X-ray/IR Correlations

- Tight correlation between X-ray and 15$\mu$m IR galaxy populations  
  (Alexander et al. 2002)
- Luminous IR starburst galaxies: dust enshrouded star formation
- $\log(f_X/f_{IR}) \sim -1.5$ or less, non-AGN by all counts
- 15$\mu$m good indicator of star-formation rate  
  X-rays also good indicator
X-ray/Submm Correlations

- X-rays from 7 of 10 bright 850 μm SCUBA sources
- 5 of 7 are AGNs
- Anti-correlation between 850 μm and X-rays?
- AGNs contribute negligibly to submm emission
- Submm emission basically powered by star-formation, so can be used to probe star formation

Alexander et al. 2003
X-ray/Radio Correlations

- Large overlap between X-ray and 1.4 GHz radio sources
- Excellent correlation between X-ray and radio luminosity, same at moderate $z$ as in local universe
- X-rays good indicator of star formation, as radio emission is

Bauer et al. 2002