The Low Metallicity ISM of X-ray Faint Elliptical Galaxies

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Metallicity of the Hot Gas: History

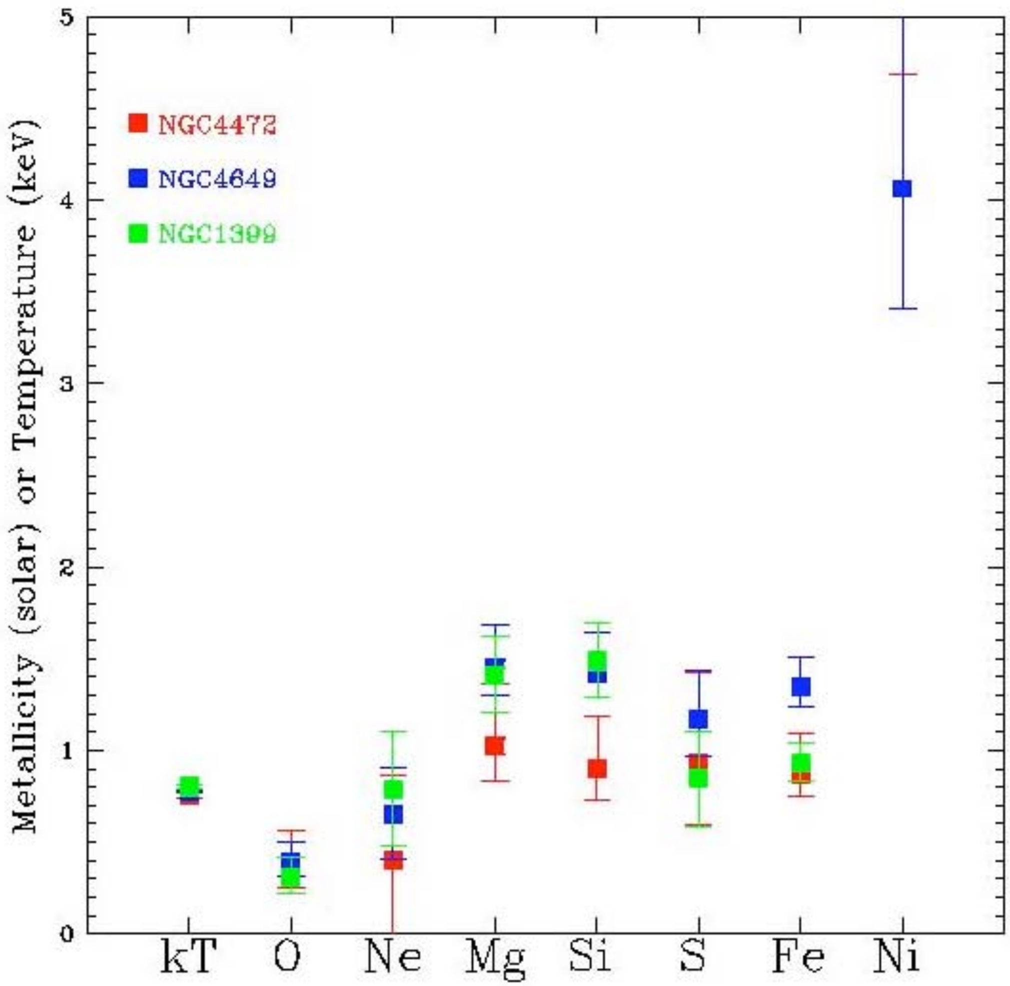
Initial studies with ASCA led to the "metallicity problem" (Arimoto et al. 1997) : hot gas: ~20% solar, stars: ≥ solar

- spectral codes (Raymond-Smith vs. MEKAL vs. APEC)
- calibration
- meteoric vs. photspheric abundances
- **treatment of LMXB component**
- **temperature gradients ("Fe bias" - e.g., Buote 2000)**

Chandra/XMM-Newton studies of high L_X/L_{opt} galaxies find ~solar abundances (e.g., Xu et al. 2002; Matsushita et al. 2003; Kim & Fabbiano 2004; Humphrey & Buote 2006).

Best spectra show non-solar abundance ratios.

Metallicity of Gas-Rich Ellipticals

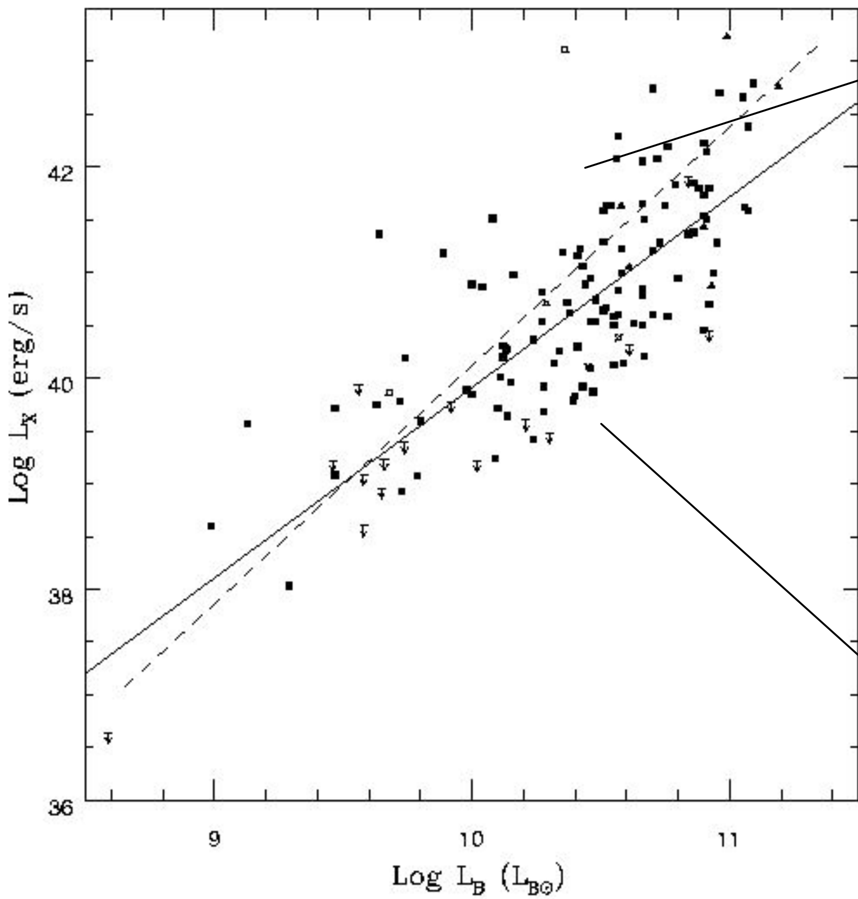


MOS+PN for X-ray bright galaxies NGC4472, NGC4649, and NGC1399

O/Fe ~ 0.3 - 0.4
Mg/Fe ~ 1.2 - 1.5
Ni/Fe ~ 3 - 7

L_X vs. L_{opt} Relation

O'Sullivan, Forbes, & Ponman 2001



X-ray bright galaxies - gas dominated

factor of ~50-100 dispersion in relation

(e.g, Trinchieri & Fabbiano 1985; Brown & Bregman 1998; Irwin & Sarazin 1998; Beuing et al. 1999; O'Sullivan et al. 2001)

X-ray faint galaxies - LMXB dominated

$L_X \propto L_{opt}^{\ 1.7\text{-}3.0}$

Metallicity of Gas in Low L_X/L_{OPT} Galaxies

For the few X-ray faint ellipticals for which the metallicity is reported in the literature, very sub-solar values were found:

NGC4697: 7% solar (Sarazin, Irwin, & Bregman 2001)

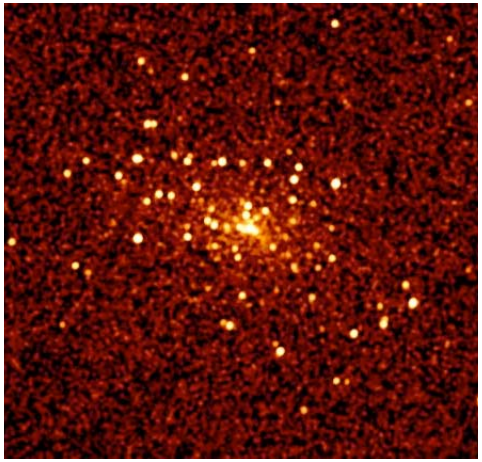
NGC1291: 13% solar (Irwin, Sarazin, & Bregman 2002)

NGC4494, NGC3585, NGC5322 : <10% solar (O'Sullivan & Ponman 2004)

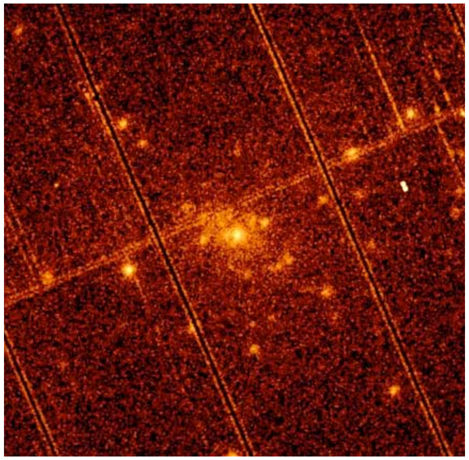
NGC1553 : ~15% (Humphrey & Buote 2006)

Potential Problems: poor statistics
stronger relative LMXB contribution
elements fixed at solar *ratios*

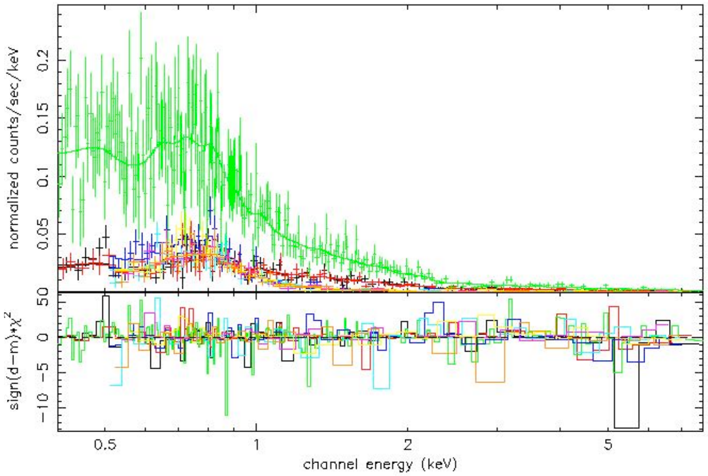
Low Metallicity Gas in NGC4697



174 ksec *Chandra*



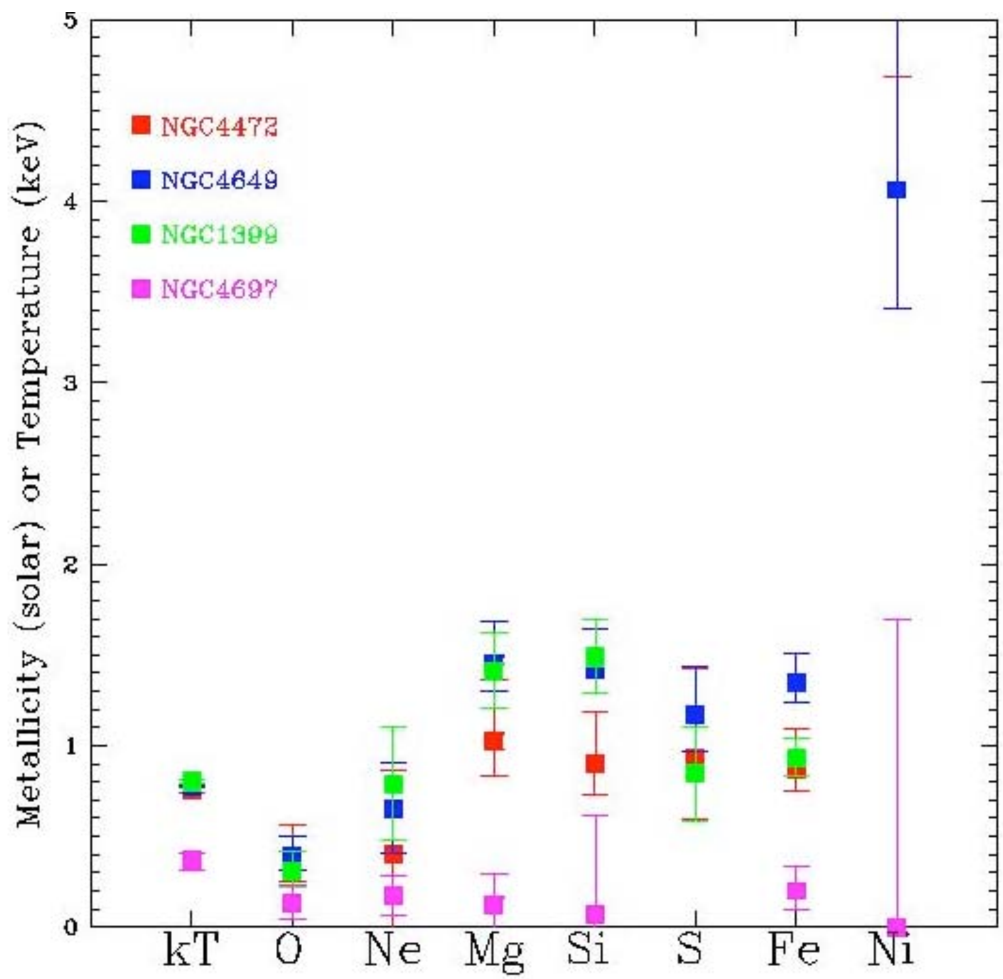
40 ksec *XMM-Newton*



$\chi_\nu^2 = 0.95/616$ d.o.f

kT = 0.36 ± 0.05 keV, O = 0.13 ± 0.09 solar , Fe = 0.20 ± 0.11 solar

NGC4697 vs. X-ray Bright Galaxies



Source of Low Metallicity Gas

How are both L_X/L_{opt} and low metallicity achieved?

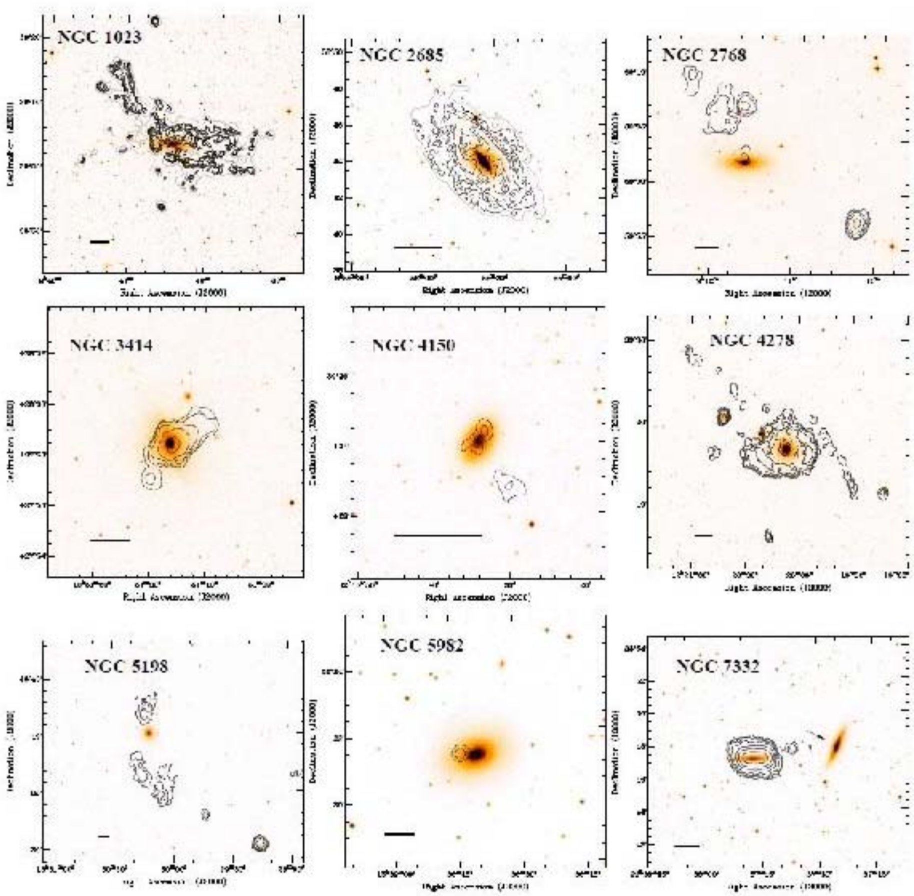
One solution: ongoing accretion of pristine gas surrounding galaxies dilutes to subsolar metallicities

observational evidence: extended HI structures observed around some ellipticals and S0s (Morganti et al. 2006; Oosterloo et al. 2007)

NGC4697: $\sim 10^8\ M_\odot \rightarrow \sim 8 \times 10^7\ M_\odot$ of accreted pristine gas

Larger, X-ray bright ellipticals: $\sim 10^{10}\ M_\odot \rightarrow$ dilution ineffective

HI Gas Around Northern Ellipticals/S0s

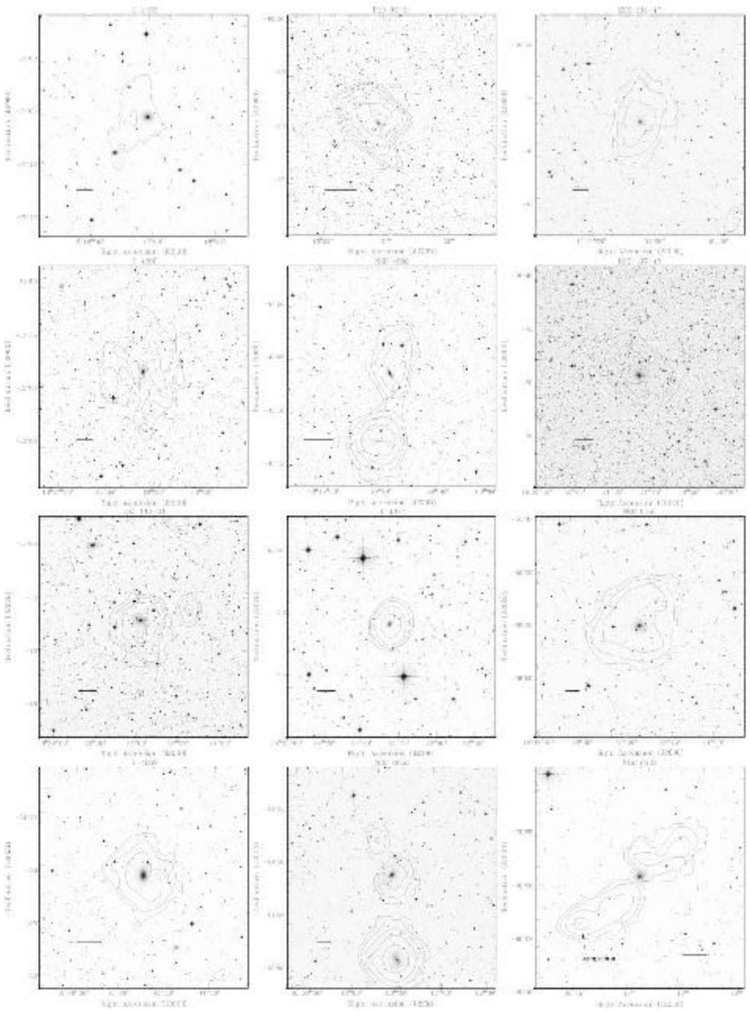


optical images/HI contours

Northern hemisphere ellipticals with 10^8 - 10^{10} $M_\odot$ large-scale HI halos

(Morganti et al. 2006)

HI Gas Around Southern Ellipticals/S0s



Southern hemisphere ellipticals with 10^8 - 10^{10} $M_\odot$ large-scale HI halos

(Oosterloo et al. 2007)

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Conclusions

Confirmed that NGC4697 has low metallicities, on an element-by-element basis.

- all X-ray faint galaxies?

Dilution of metal-rich ISM with pristine gas from HI structures surrounding isolated galaxies?

- predicts metal-rich ISM in X-ray faint galaxies in clusters
- predicts the same abundance ratios as in X-ray bright galaxies

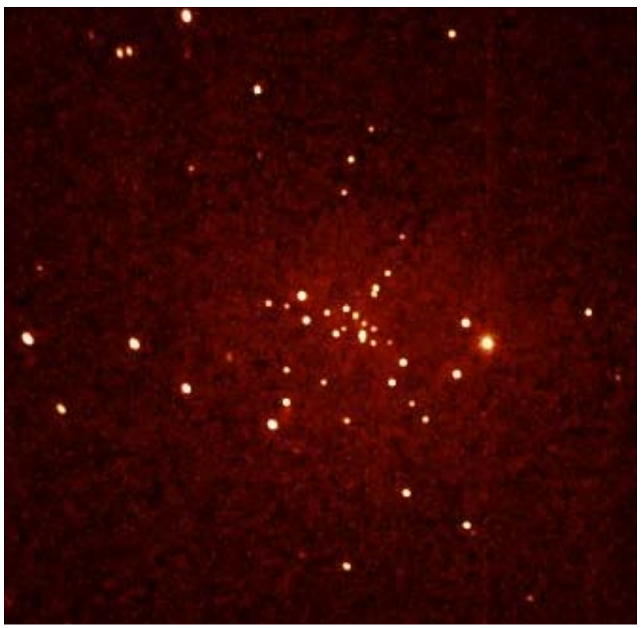
➡ can be addressed with deep *XMM-Newton* observations coupled with existing deep *Chandra* observations

Bulge of M31

Old, metal-rich stellar population

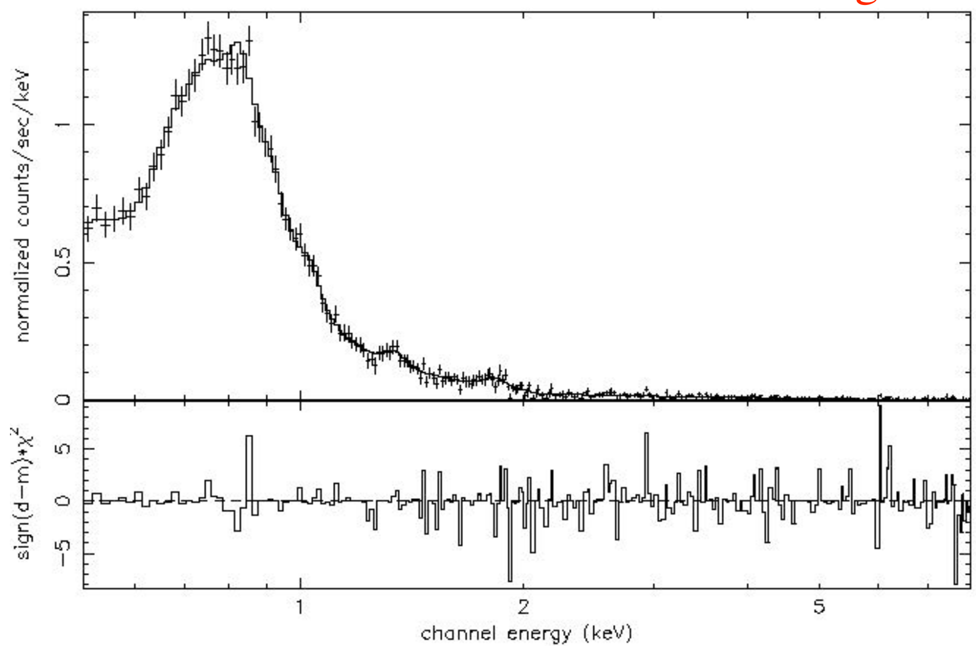
kT ~ 0.3 keV (Shirey et al. 2001; Takahashi et al. 2004)

L_X/L_{opt} comparable to X-ray faint ellipticals



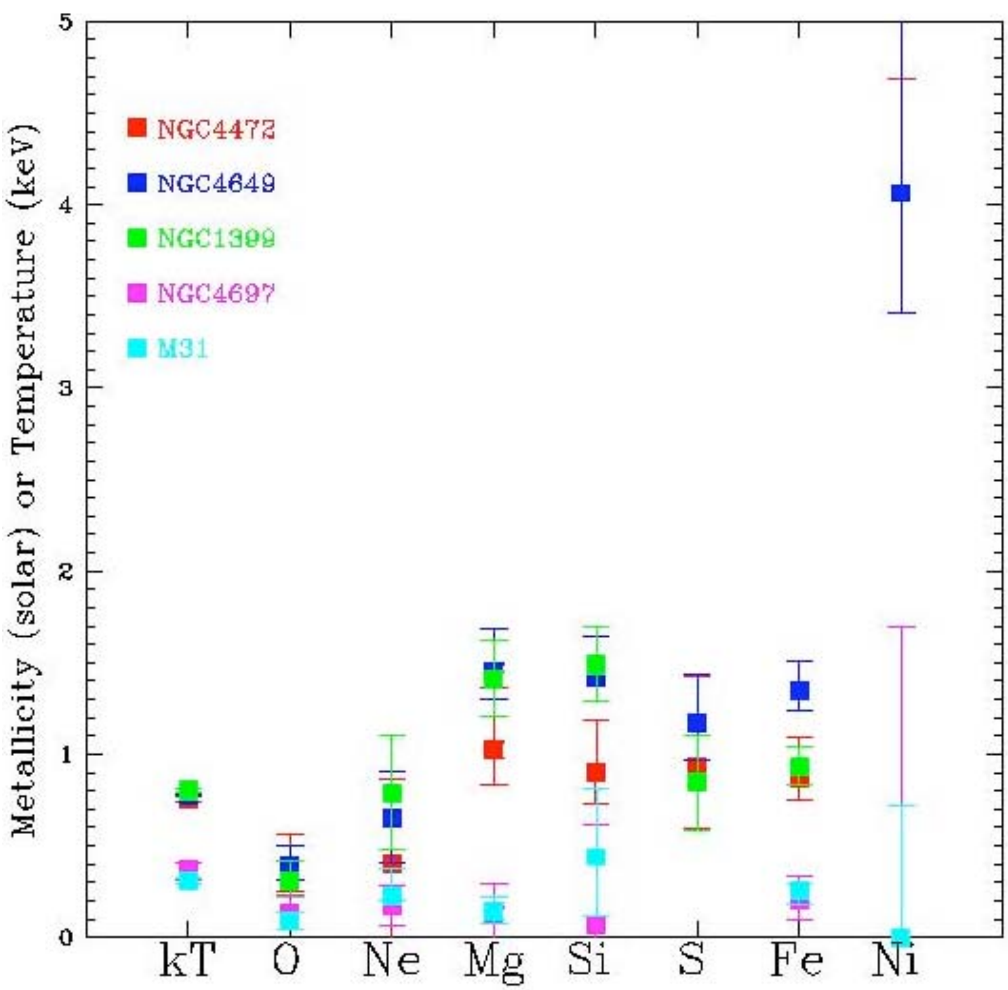
38 ksec *Chandra*

2 arcmin region



$\chi_\nu^2 = 1.11/235$ d.o.f

Bulge of M31

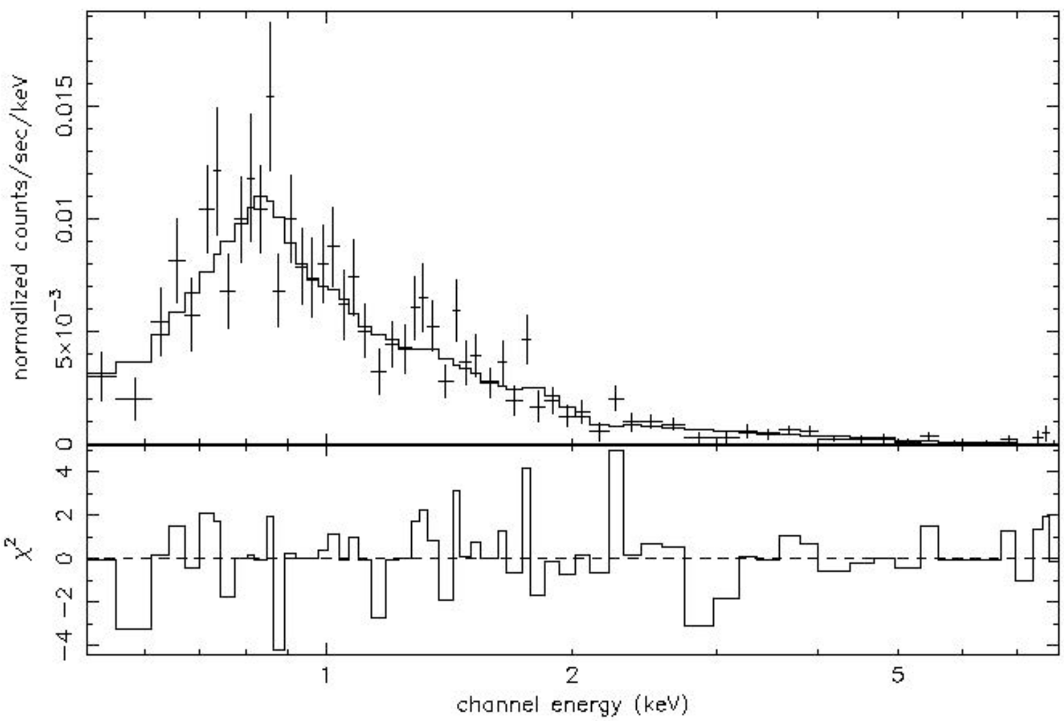


kT = 0.31 ± 0.02 keV
O = 0.09 ± 0.05 solar
Ne = 0.29 ± 0.09 solar
Mg = 0.15 ± 0.07 solar
Fe = 0.23 ± 0.06 solar

<u>Total 0.5 - 2.0 keV flux</u>
Source: 85%
Background: 15%

<u>Source 0.5 - 2.0 keV flux</u>
Gas: 70%
Stellar: 30%

M32 - Stellar X-ray Sources

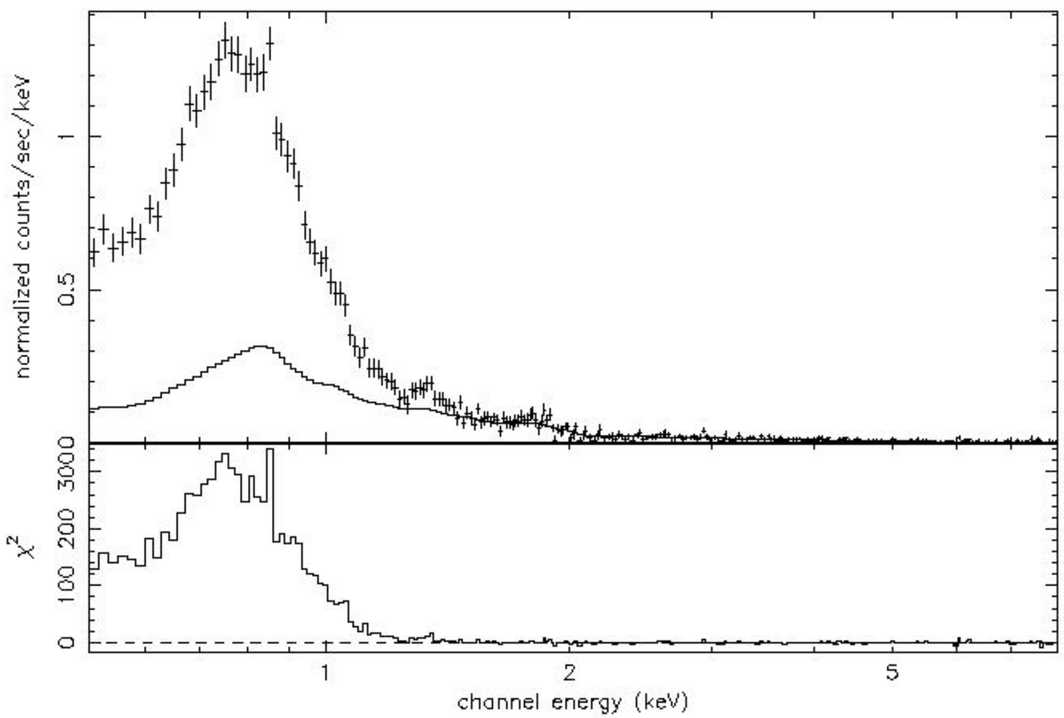


M32 does not contain any X-ray-emitting ISM

Only X-ray emission is from stellar sources: accreting white dwarfs, active stellar coronae, etc. (Revnivtsev et al. 2007).

Two component APEC+power law fits data well.

M31 - Stellar X-ray Sources



Use M32 spectrum, scale up to 2-8 keV flux from M31 spectrum.

0.5-2 keV flux dominated by an additional component: the ISM

Stellar Source for Soft Component?

NGC4697

$L_{X,gas}$(0.5-2 keV): 2.1 x 10^{39} ergs s^{-1}

L_K : 9.1 x 10^{10} $L_\odot$ (David et al. 2006)

$L_{X,gas}$(0.5-2 keV)/L_K : **2.3 x 10^{28}** ergs s^{-1} $L_\odot^{-1}$ (similar for M31)

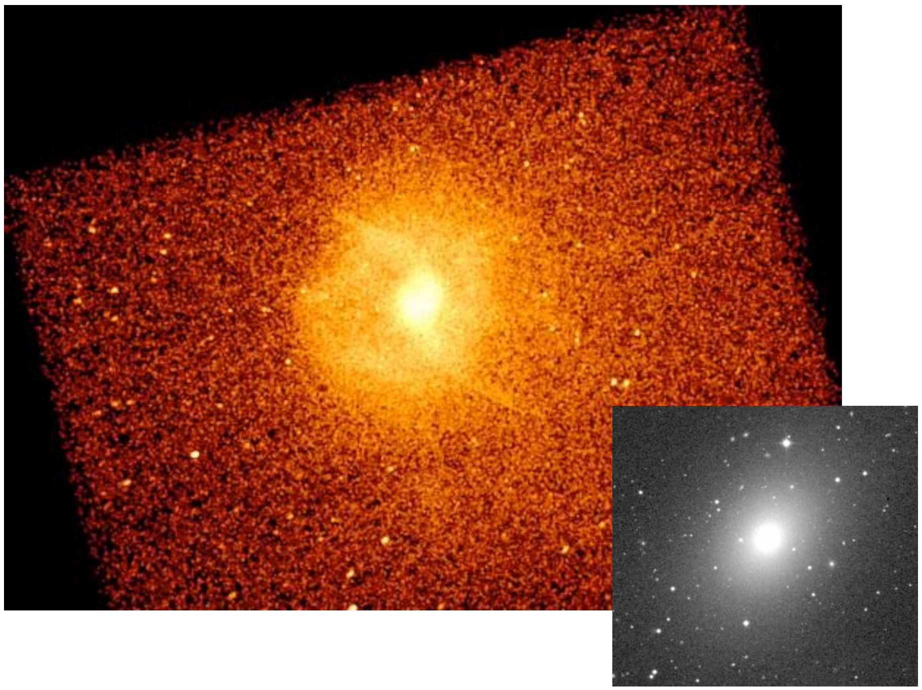
M32 (Revnivtsev et al. 2007)

$L_{X,stellar}$(0.5-2 keV)/L_K : **4.1 x 10^{27}** ergs s^{-1} $L_\odot^{-1}$

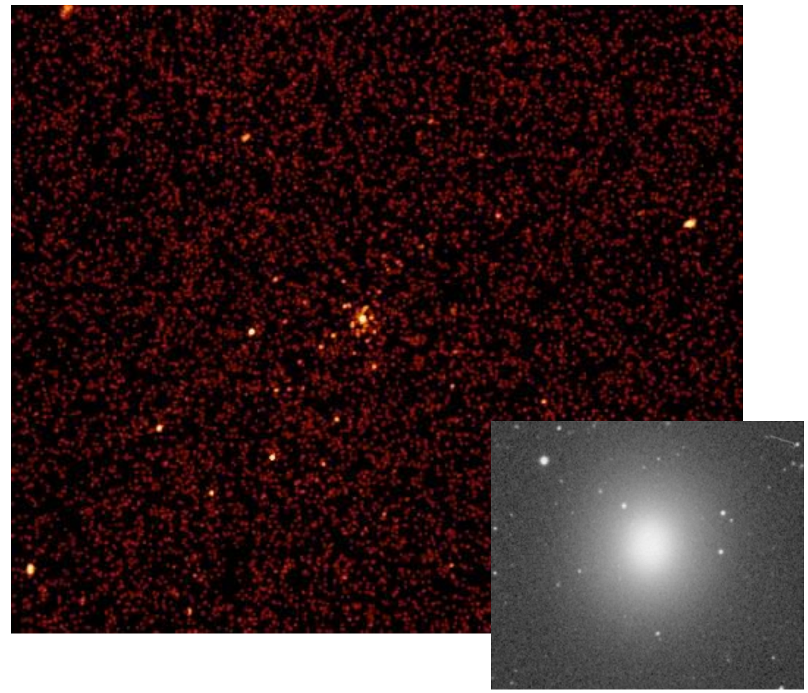
Gas component of NGC4697 **5.6x** larger than expected stellar contribution.

X-ray Bright vs. X-ray Faint

NGC4636 (M_V = -21.3)



NGC4494 (M_V = -21.5)



NGC4494: $L_{X,total}$ (ROSAT) - 3×10^{39} ergs s^{-1}

$L_{X,gas}$ (*Chandra*) - 4×10^{38} ergs s^{-1}